UNIVERSITY OF NAIROBI

SCHOOL OF THE BUILT ENVIRONMENT

DEPARTMENT OF ARCHITECTURE AND BUILDING SCIENCE

AN INVESTIGATION OF ENERGY EFFICIENCY AND OCCUPANCY LEVELS OF GLASS-CLADDED AND BIO-CLIMATICALLY DESIGNED BUILDINGS; - A CASE OF CBD, NAIROBI.

BY NDUTA DAVID KIBERA

A thesis submitted in partial fulfilment of the requirements for the Award of the Degree of Master of Architecture in the Department of Architecture and Building Science, University of Nairobi.

2023

DEDICATION:

To the Almighty God, my anchor and provider in all ways. My wife Wairimu Kibera for your support, prayers, and believing in my vision. My children Prince Kibera and Nduta Kibera who I will inspire to greater heights.

DECLARATION

I hereby declare that this thesis represents my own work and to the best of my knowledge, it has not been presented in any other university or Institution for the purpose of awarding a degree. This thesis is submitted in partial fulfilment of the examination requirements for the award of a Master of Architecture degree, in the Department of Architecture, University of Nairobi.

Signed: .... Date: 07.08.2023..............................

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ABSTRACT

Today, buildings are thought to require more than 50% of the total energy consumed worldwide. Energy-efficient building design depends on a choice of suitable methods that are compatible with the local climate. The two crucial factors in tropical climates that need careful consideration are cooling technology and electrical appliances (including the lighting system).

The main focus of this thesis is on building design for tropical climates. The main objectives are to establish the current state of knowledge on the energy-efficiency of bioclimatic buildings in tropical climates, with a particular emphasis on Nairobi. To look into the energy efficiency and occupancy levels of glass-cladded and bioclimatic buildings in Nairobi. And finally, offer recommendations for plans and regulations that Nairobi buildings should implement to become more energy efficient.

The research employs a combination of data from actual performance and simulation tools to evaluate energy efficiency. Three models with the thermal behaviour of both bioclimatic buildings, glass-cladded and one that is neither glass cladded nor bioclimatic have their energy simulations carried out. Additionally, energy efficiency monitoring is done on-site in a few buildings to record actual patterns of consumption of energy and assess how well they function in actual settings.

The research also looks into user comfort in these buildings and the level of occupancy. Data on occupant satisfaction, indoor environmental quality, and thermal comfort are gathered through surveys and observations. The results are then contrasted between the two building types to look for any connections between strategies for design and user satisfaction.

After gathering data from the literature and the results of case studies in Nairobi, a strategy for developing energy-efficient buildings is presented. In a nutshell, the important components in reducing energy consumption are the design of the building including site selection and planning, building form, plan and

envelope, use of energy-efficient materials, use of renewable energy resources, cooling technology, and appliance efficiency. This thesis will compare the occupancy levels of bioclimatic and glass-cladded buildings in Nairobi.

An energy-efficient building ensures that residents have a comfortable living environment while using the least resources and the least amount of energy. The construction process itself, moving through the building's operating maintenance cycle, and ending with its demolition are all included in measures to make a building energy-efficient. For its occupants, an energy-efficient building maintains complete functionality and thermal comfort. The demand for energy-efficient building designs grows as a result of rising energy prices and the impending realities of the energy crisis.

The study's findings offer critical new information about the energy efficiency and occupancy experiences of glass-cladded and bio-climatically designed buildings. The study advances knowledge of sustainable building design and offers useful data to architects, designers, and legislators that are considering employing energy-saving and environmentally conscious building practices.

The recommendations from the study will be used to form policy and design guidelines for energy-efficient buildings in tropical climates.

01: INTRODUCTION

Chapter One

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1.1 Problem Statement

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1.8 Organization of the Study

1.9 Definition of Terms

Figure 2 Image showing Nairobi Skyline.

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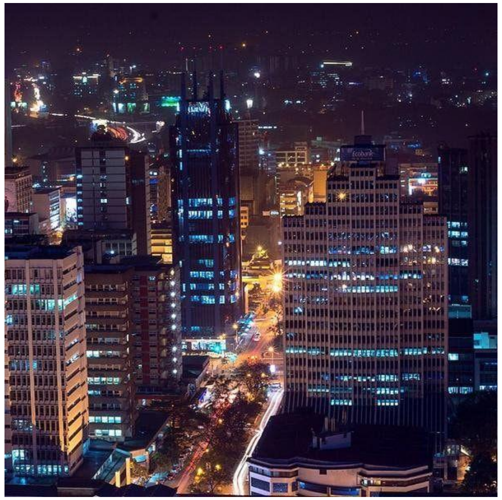


Figure 1 Image showing Nairobi Skyline.

Source: ff7e17a34186c7e81f05a7af459e2222.jpg (600×600) (pinimg.com)

1.0 Background of the Study

In terms of the health of the economy and the prosperity of society, Nairobi is improving. More and more people are residing in modern buildings, the majority of which are masonry, concrete, and glass buildings typical of Western cold climate architecture. Due to the extra heat that is trapped in the building walls and the inadequate ventilation, this style is not considered suitable for areas with tropical climates. However, it is well-known and largely accepted in Nairobi and the surrounding area. Additionally, several useful appliances, including an air conditioner, a water heater, a refrigerator, lighting, a microwave, a computer, a large-screen television, and others, are well-equipped in buildings. It is now typical for buildings in urban areas to have these pieces of equipment. Figure 1 and 2 shows images of the Nairobi skyline at night.

Recently and gradually, stakeholders and practitioners in Kenya's building sector have come to understand the urgent need for a more sustainable approach to building design and construction. It is thought that the only option for the nation to control the rising rate of pollution and to reduce the energy consumption of the building sector is to introduce strict environmental and sustainable criteria in building practice. The general public is becoming more aware of the importance of implementing sustainable and environmentally friendly methods. Moreover, Kenya will not meet the CO_2 emission reduction of 30 % target by 2030. Vision 2030 outlines the goals to be a nation that has a clean, secure, and sustainable environment. Other relevant policies include the Climate Change Act, of 2016, the National Climate Change Framework Policy 2016, Kenya's National Climate Change Action Plan 2018-2022, The

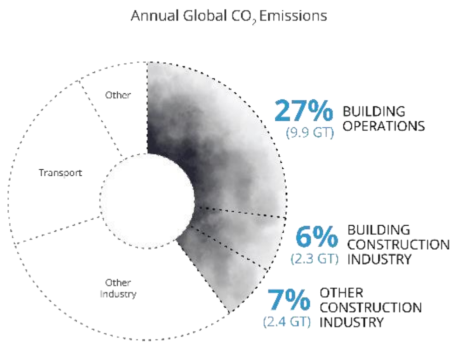


Figure 3 Image showing Annual Global C02 Emissions.

Source: Why the Building Sector? – Architecture 2030

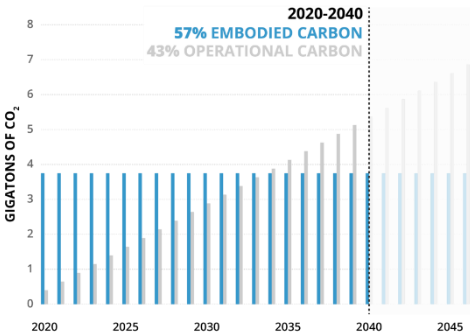


Figure 4 Image showing graph of embodied carbon against operational carbon.

Source: Why the Building Sector? – Architecture 2030

Built Environment Bill 2017, the Housing Bill 2017, and the Paris Climate Agreement of 2015, in which Kenya is a signatory (GOK, 2017). Green building rating tools such as LEED-US (Leadership in Energy and Environmental Design), BREEAM-UK (Building Research Establishment Environmental Assessment Methodology), as well as the Kenyan Building Code, has specifications for energy-efficient buildings.

Failure to promote low-carbon and energy-efficient building practices would undoubtedly prevent the drawbacks of underperforming buildings for decades. The most appropriate and effective solutions to this energy issue are climate-responsive buildings, especially in a developing country like Kenya where energy needs are increasing.

Buildings use a lot of energy, which not only harms the environment but also has an economic cost as energy prices rise. Implementing comprehensive policies that promote energy-efficient building practices, such as better insulation, energy-efficient appliances, smart building systems, and the utilization of renewable energy sources, is essential to resolving this problem.

Stakeholders, including governments, building owners, architects, engineers, and tenants, must work together and take coordinated action to reduce the issue of energy consumption by buildings. This could entail passing and implementing tougher building codes and regulations, offering grants and financial incentives for energy-efficient retrofits, promoting sustainable building design and construction, and raising knowledge of energy-saving techniques.

We can dramatically reduce greenhouse gas emissions, lessen our dependency on fossil fuels, reduce energy prices, and create healthier and more sustainable living and working environments by tackling the issue of energy use by buildings.

1.1 Problem Statement

One of the most important considerations in the design and decision-making phases for many architectural design processes over the past few decades was energy efficiency and comfort conditions in buildings, (Hirst 1986, Nieboer 2012). Energy-efficient buildings reduce both resource depletion and the impacts of pollution generated by energy production. (Nieboer 2012 & Kreith et al. 2011).

Energy-efficient buildings most of the time are criticized to be unappealing. Implementation of buildings whose design is based on energy-efficient systems; that include thermal insulation and acoustics, natural ventilation, and lighting, should also be aesthetically appealing. The main motivators of energy efficiency in buildings are; the increasing global population, decreasing fossil energy resources, rising emission of harmful gases, global warming, and climate change. It is estimated that more than 50% of the annual energy consumed in the world is used in buildings today. Therefore, it begs the question of how do we design buildings to ensure they are energy-efficient without compromising their aesthetics.

Buildings consume a lot of energy, which not only harms the environment but also has an economic cost as energy prices rise. Implementing comprehensive policies that promote energy-efficient building practices, such as good design practices that respect climate, better insulation, energy-efficient appliances, smart building systems, and the utilization of renewable energy sources, is essential to resolving this problem. Glass-cladded buildings have become a norm in tropical climates. One wonders whether these buildings are energy-efficient. What is the percentage of occupancy per square metre against the bioclimatic energy efficient-buildings?

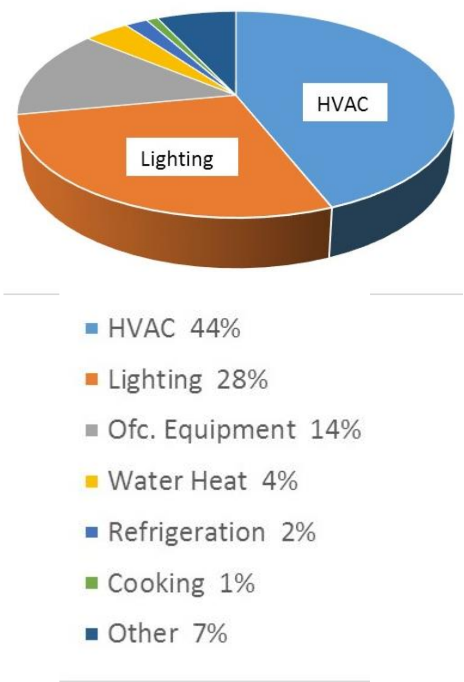


Figure 5 Image showing chart illustrating Commercial Building's Energy Consumption. Source: Building-Energy-Consumption-Chart.jpg (836×494) (bluehatmechanical.com)

Figure 6 Image showing One Africa building in Nairobi.
Source: R.7343decf8db8135192b3ed6e446ff576 (809×1080) (bing.com)

1.2 Research Objectives

1. To establish existing knowledge on the energy efficiency of bioclimatic buildings in tropical climates with a focus on Nairobi.
2. To investigate the energy-performance and occupancy levels of glass-cladded buildings and bioclimatic buildings in Nairobi.
3. To make recommendations for guidelines and strategies that can be developed for buildings in Nairobi to make them energy-efficient.

1.3 Research Questions

1. What is the existing knowledge on energy-efficient bioclimatic buildings in tropical climates with a focus on Nairobi?
2. What is the occupancy and energy performance of glass-cladded buildings and bioclimatic buildings in Nairobi?
3. What guidelines and strategies can be developed for buildings in Nairobi to make them energy-efficient?

1.4 Justification of the Study

Energy is becoming more expensive, and a crisis is on the horizon. Energy-efficient building designs must be offered. After industries, buildings are responsible for the second-highest energy consumption. By offering an optimized blend of passive solar design techniques, energy-efficient machinery, and renewable energy sources, an energy-efficient building strikes a balance between all aspects of energy use in a building.

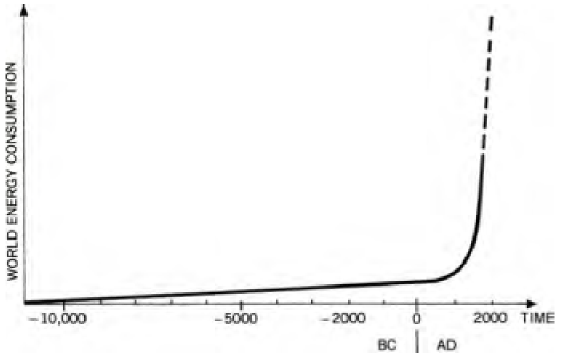


Figure 8 Image showing a graph of similarity in Exponential growth in world energy consumption and population growth.

Source: Heating, Cooling, Lighting; Sustainable Design Methods for Architects by Norbert Lechner

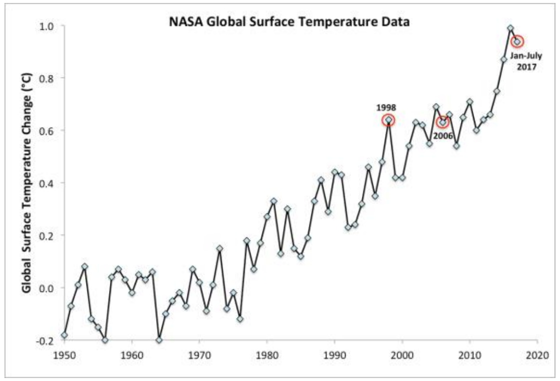


Figure 7 Image Showing a graph of Global Surface Temperature Data.

Source: 1408.png (1240×844) (guim.co.uk)

Fig. 6 shows the image of the One Africa building in Nairobi.

There is a trend in this era of designing tall buildings, dense residential apartment blocks emerging technology, growing population, urbanization, creation of transparent and porous surfaces on buildings, and land constraints in cities. All these raise the energy consumption in buildings. Case studies will be undertaken for an effective understanding of the significant shift in building energy-efficient design which occurred as a result of the 1973 oil crisis. Societies have to come up with diverse solutions as a result of the abrupt rise in energy prices and the challenges of accessing energy supplies. Understanding the importance of energy efficiency in buildings, the return to passive design principles (Commission of EU, 1991), for an energy saving consciousness development. The most efficient use of limited energy resources should be encouraged.

There is a problem with climate change. In 1990 the thinning of the ozone layer increased. With this, the concept of green buildings alongside energy efficiency has been introduced. Figure 8 shows the graph of global surface temperature data.

This research will apply a **mixed approach**, comprising several tools and methods. It will start with a **literature study:** the history of energy-efficient Buildings, energy-efficient buildings in the last Century, designing energy-efficient buildings considering the life cycle of a building: energy-efficient design techniques during the pre-building phase of a project, energy-efficient designing methods in the building phase, energy-efficient methods in post-building phase. The study of bioclimatic architecture, glass cladded buildings in the tropical climate, and occupancy levels of both bioclimatic energy-efficient buildings against glass cladded buildings. It will be followed by a site survey to collect information about the occupancy levels and energy efficiency of both glass-cladded and bioclimatic buildings. Semi-structured interviews, site observations, and field notes. will be the main tools used, together with photo documentation. **Interviews** will be conducted within the case, to investigate energy consumption by buildings occupancy levels and rates by tenants per metre square. Energy simulations of three buildings within Nairobi will be carried out, analysed, and recommendations are given.

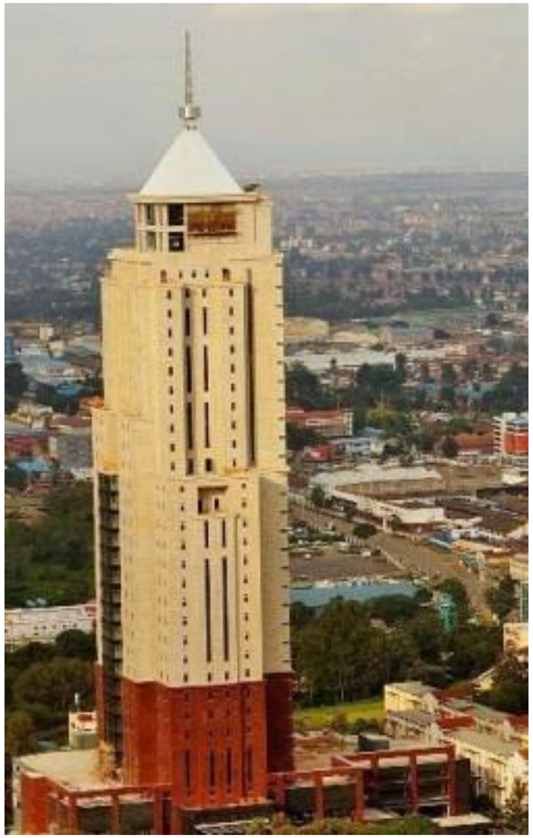


Figure 9 Image showing UAP Old Mutual Building in Upper hill Nairobi.
Source: upp2-252x400.jpg (252×400) (biggestkaka.co.ke)

Figure 10 Image showing the Nairobi skyline.

Source: Nairobi skyline - Search (bing.com)

Figure 11 Image showing map of Africa highlighting Kenya.
Source: R.f66b24d2d524e921603e08c6c88903fd (1071×1164) (bing.com)

Figure 12 Image showing a Map of Kenya highlighting Nairobi.
Source: Author Modified, 2023

1.5 Significance of the Study

The findings of this study will lead to the addition of strategies for energy-efficient and bioclimatic buildings in tropical climates. This is important in the development of appropriate design principles in tropical climates. This will save on the reliability of fossil fuels and the reduction of Co2 emissions, global warming, and climate change. The use of renewable energy resources is strengthened while decreasing reliance on fossil resources, achieving high-performance buildings that produce more energy than their consumption.

1.6 Scope and limitation of the Study

This study is limited to Nairobi County. The research will involve the study of glass-cladded and bioclimatic buildings in the CBD and its environs. An analysis and thorough study should be carried out to determine their energy efficiency and occupancy levels. It will involve the study of office buildings. This will provide a better understanding and information on buildings that are energy efficient for maximum occupancy and return on investment. Other typologies such as malls or residential buildings will not be considered since their energy use patterns are different. Only three buildings will be simulated ranging from glass cladded to bio-climatically designed buildings. The study is limited to electrical energy consumption because most office buildings use this form of energy. The use of petrol and diesel to power generators is often used during power blackouts. The use of gas in office buildings is almost non-existent in Kenya. The theoretical scope of the study is environmental science through the study of energy-efficient buildings. Electrical bills used in the study were for the year 2022. Earlier bills could not be retrieved by building managers and caretakers.

Figure 13 Image showing the Skyline of Westlands Nairobi.

Source: R.da357e52d94976de96839ce9d65d29b8 (960×1195) (bing.com)

1.7 Research Methodology

This chapter describes the study methodology utilized in the research in Nairobi. It emphasizes methods and sources of data collection that the author uses in the field. It explains briefly the reasoning for each approach, how it was built, and the goal of the analytical approach. This research aims at documenting both glass-cladded and bioclimatic buildings' energy-efficiency and occupancy levels.

The research will be undertaken through published journals, written books, past documented thesis, and fieldwork of case studies in Nairobi. In summary, it will involve:

1.7.1 Literature Review of Published Material

The author will rely on published books, journals research papers, and articles that will help in surveying the topic of study. This literature will help in the collection, analysis, and presentation of data from the field. These published materials will be in the list of references.

1.7.2 Internet Sources

Various sources will be linked to some of the details found herein. A full list of these will be given in the References section.

1.7.3 Fieldwork

Sampled field study of Nairobi to be carried out. In the course of the field study, interviews will be conducted, sketching, photographs and measurements will be taken, and observations made. Computer simulations will be carried out for the analysis of the data collected.

1.8 Organization of the Study

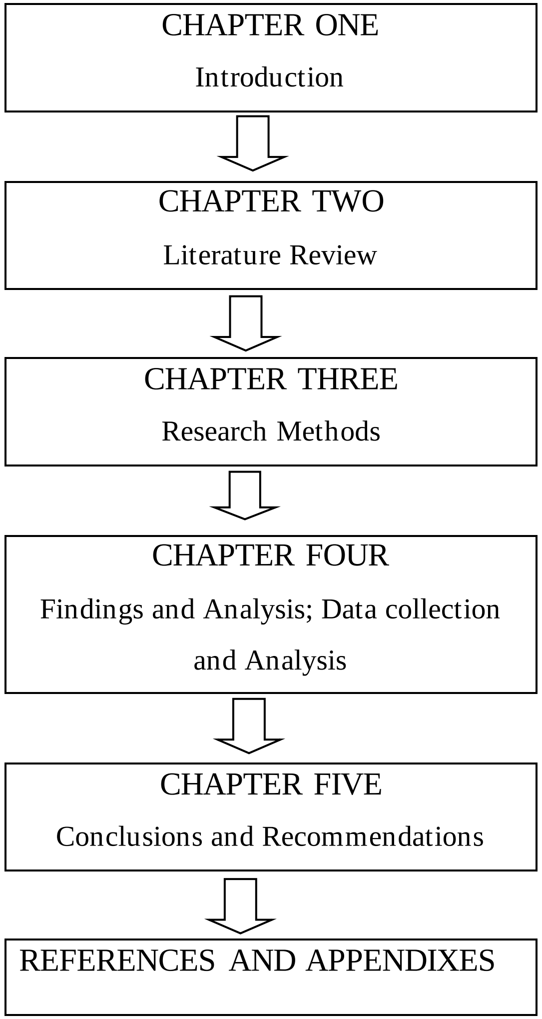


Figure 14 Image showing the flow chart of the study. Source: Author: 2023

Chapter One: Introduction

This chapter serves as an introduction to the subject of the report, beginning with the background of the study. The research problem, questions, and objectives have been set out in this chapter. The reason for the project was specified, followed by the importance of the study and the scope and limitations. Chapter One begins by highlighting how the analysis methods will be applied and eventually explains the organization of the report. Fig. 14 shows the organization of the study. The chapter concludes with the organization of the study definition of key terms and a list of abbreviations.

Chapter Two: Literature Review

This chapter gives the theoretical framework for the study through analysis of past and ongoing research on energy-efficient buildings. The first part of the review will begin by looking at strategies for energy-efficient buildings from historical approaches to the present day. The study of glass-cladded buildings and application in tropical climates. And finally, to create factors for occupancy and energy-efficiency in buildings in tropical climates a framework will be used in fieldwork, data collection, documentation, and analysis.

Chapter Three: Research Methods

This chapter discusses the research methodology that will be used in the field, including data collection, analysis, and presentation.

Figure 15 Image showing pollution due to energy production.

Source: Climate-Change-2-EPA.jpg (990×743) (independent.co.uk)

Figure 16 Image showing atmospheric pollution in China.

Source: R.724866f04d71fd4568cb67ef8f2a4bcd (1642×1094) (bing.com)

The investigation uses the case study research method with a mixed method of quantitative and quantitative data collection and analysis to understand energy-efficient buildings and their occupancy to make a case for return on investment. Primary data collection methods include observation, interviews, and climatic data recordings which will be presented in written narrative, sketches, photographs, architectural drawings, graphs, charts, and tables. Secondary data for this investigation will be collected and analysed from existing literature, internet sources, and academic journals. Primary data will be collected and analysed through observation, sketches, and energy simulation analysis of bioclimatic and glass-cladded buildings in Nairobi.

Chapter Four: Findings and Analysis

This chapter analyses and presents primary data collected from Nairobi CBD and its environs, through interviews, observations, sketches, photographs, architectural drawings, graphs, charts, and tables. The region of the case study was chosen because of the current upsurge in the construction of commercial buildings, as well as its population growth parameters.

Chapter Five: Conclusion and Recommendations

This chapter will offer a detailed description of each chapter of the final part of the report. It sets out the essential results of the study and proceeds to provide guidance. These suggestions are intended to contribute to the strategies for efficient buildings within tropical climates. Furthermore, making recommendations for further study and global sustainable development to mitigate global warming and climate change.

1.9 Definition of Terms

i. Bioclimatic Architecture: this refers to the design of buildings depending on local climate, making use of solar energy and other environmental sources, to provide thermal and visual comfort

ii. Cross-Ventilation: a philosophy based on the necessity of ensuring a fresh and comfortable indoor climate. This is done with negligible energy consumption and at a low cost (Hyde 2008)

iii. Energy-efficient building: a building that creates comfortable living conditions inside the dwelling with the least possible amount of energy consumption maximising efficiency in the use of resources (Sustainable Fuel Technologies Handbook, 2021)

iv. Glass-cladded building: the use of glass as a primary material and its implications on the building's aesthetics, functionality, and performance, encompassing both the architectural and technical aspects.

v. Renewable Energy: refers to energy sources that are naturally replenished and have a minimal impact on the environment.

vi. Examples include; solar energy, wind energy, hydropower, geothermal and tidal energy.

vii. Infiltration: uncontrolled leakage around doors and windows and through joints, cracks, and faulty seals in the building envelope.

viii. The 'greenhouse effect' is a natural warming process of the sunspaces. When the sun's energy reaches the transparent surfaces, some of it is reflected back to space, and the rest is absorbed. The absorbed energy warms the sunspaces, which then emits heat energy back toward space as long-wave radiation. (N'Soukpoe-Kossi and Leblane 1990).

02: LITERATURE REVIEW

Chapter Two

2.0 Introduction

2.1 History of Energy-Efficient Buildings

2.2 Energy Efficient Buildings in the 20th Century

2.3 Designing Energy-Efficient Buildings Considering the Energy Life-Cycle of a Building

2.4 Tropical Climate

2.5 Bioclimatic Architecture

2.6 Glass-Cladded Buildings in the Topical Climate

2.7 Occupancy Levels of both Bioclimatic Energy-Efficient Buildings against Glass Cladded Buildings

2.8 Literature Review Conclusions

2.0 Introduction

Figure 17 Image showing the Nairobi Skyline.

Source: h_52904648-e1498658563544.jpg (2200×1206) (qz.com)

This chapter's goal is to create a theoretical basis for the research's primary arguments. It examines the energy efficiency and occupancy levels of glass-cladded buildings and bioclimatic buildings. Looking into the history of energy-efficient buildings and developing them with their lifecycle in mind will help to understand this inquiry. Indulge in learning about the tropical climate, bioclimatic buildings, glass-cladded buildings their energy efficiency, and occupancy levels. Examining successful case studies to draw lessons.

Therefore, this chapter serves as the study's theoretical basis. Determining the energy efficiency and occupancy levels of both glass-cladded buildings and bioclimatic buildings, as well as their applicability and relevance in a tropical climate like Nairobi is the author's honest endeavour. Figures 17-19 show the skyline of Nairobi CBD.

Figure18 Image showing the Nairobi Skyline.

Source: R.303fc58b1a670546b0aec1a418e45970 (2592×1944) (bing.com)

Figure 19 image showing the Nairobi Skyline.

Source: R.6bc232070ac39c76cc0e75eb32514bc5 (2461×1394) (bing.com)

Figure 20 Image showing a Greek Architectural Masterpiece which were energy efficient.

Source: DSC_0157-5c75728e46e0fb0001a5ef15.jpg (1500×995) (thoughtco.com)

Figure 21 Image showing Renaissance architecture.

Source: OIP.lN3ov80j5HvfTxWkrGcGPAHaFC (474×322) (bing.com)

2.1 History of Energy Efficient Buildings

The ability of man to use and adapt natural processes to enhance living conditions dates back to the dawn of time, and homes and the methods used to build them are just one example.

Before the 20th century, people constructed good practice rules that they passed down from one generation to the next, even if the phrase "energy-efficiency" was not as widely used as it is today. The process employed to construct a house was therefore based on earlier research and experiments. Those construction techniques could be improved and preserved in this way, which was a good solution at the time.

Each era added something new or enhanced the methods already in use, but it is amazing to note that modern energy-based systems have historical precedents.

It has been discovered that people used partially buried dwellings as a method to provide more stable indoor temperatures in the Carpathians region in 5500 BC. Later, Essenian groups from the Middle East, Native American tribes, and Cappadocians utilised the advantages of the ground's thermal qualities in their homes. The Persian "Badghir" (wind tower), where the wind and earth energy were used in designated routings to ensure inside comfort, is an outgrowth of earlier structures. This approach was applied to a unique Roman Empire room design known as "Heliocaminus." The building industry had seen significant advancements during ancient times. They were retained throughout centuries, including the Middle Ages, and were regarded as traditional, serving as a way to represent elements of the national character.

Figure 22 Image showing MIT Solar House 1.

Source: mit_solar_house_i_1939.jpg (1382×919) (yale.edu)

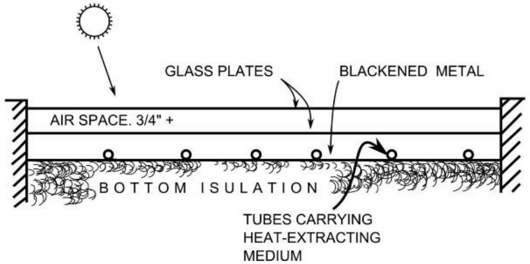


Figure 23 Image showing solar collectors on MIT Solar House 1.

Source: mit_solar_house_i_1939_panel_diagram.jpg (1382×679) (yale.edu)

The Renaissance left its impact on a variety of sectors, from culture to science, architecture, and technologies, and brought to the fore and emphasized the virtues of ancient times.

The 19th century saw the maturation of classicism in science and advancement in the field of architecture. By traditional definition, this was one of the most significant periods for scientific discovery. In addition to creating the technical breakthrough, scientists also created a fundamental scientific foundation through numerous treatises, books, dissertations, etc.

The scientific research in the building industry during the last decade of the 19th century included studies of the thermal insulation effect in the heat transfer domain, the production and transportation of moisture in the walls, multilayer window configurations, etc. At this point, preheating the air in the basement service room became a standard practice. Convective air circulation toward the top floors served to start the ventilation process in this manner.

Researchers already had the theoretical and technological underpinnings to organically fulfil the wish for a future energy-efficient home at the turn of the 20th century. Carrier developed the electric air conditioning system and later published a psychometric chart.

The 1930s buildings "MIT Solar House 1" and "House of Tomorrow" by George F. Keck and Hoyt C. Hottel revealed significant heat gains from the Sun. The two structures pioneered the idea of energy efficiency in buildings using methods of computation, design, and construction based on science.

Figure 24 Image showing House of Tomorrow" by George F. Keck and Hoyt C. Hottel.

Source: cca0157a-b9b5-4d5f-8c52-d2d759e6799b.jpg (960×720) (wbez.org)

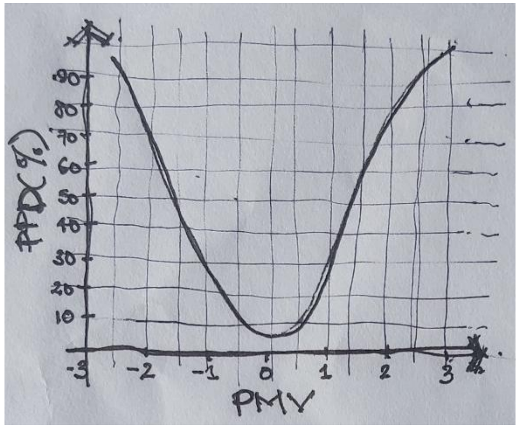


Figure 25 Image showing Fanger's model.

Source: Author Modified, 2023

The thermal architecture of the components and technologies, especially solar collectors, was crucial to the success of these structures. Later, new technical solutions were accessible. The enhancement of insulation properties was becoming commonplace. The next 10 years were devoted to the second World War and the accompanying rebuilding. The 1940s saw a slowdown in the advancement of home technology and a dearth of significant issues relating to building energy.

The seasonal energy storage system was one of the most crucial issues in the building industry at the end of the 1950s. The initial long-term thermal energy storage project came to fruition in 1984 in Germany. The passion for processing thermal load data by computer in the 1960s led to the development of a system for assessing a building's energy efficiency. At this point, the methodologies for estimating the energy load of buildings began to be supported. The Degree Day Method, the Bin-Method, and the Modified Bin-Method were later created by the researchers. Fanger made a significant contribution to the measurement of thermal comfort, which determined the required thermal load. The environment outside also plays a significant influence in his model. The Fanger model is still one of the most popular comfort models today. Figure 25 shows a graph of Fanger's model.

The 1973 oil crisis led to an increase in interest in buildings' energy efficiency. Airtightness of buildings, super-insulation, heat recovery in ventilation systems, use of triple pane windows, and passive technologies that were primarily focused on the use of solar thermal energy were topics that people became more concerned about. Older ideas are now redefined by more modern ones, as Brenda and Robert Vale indicate in their descriptions of

Figure 26 Image showing The Saskatchewan Conservation House" (1976).
Source: saskatchewan_house_orr2_kleiner.jpg (499×333) (passipedia.org)

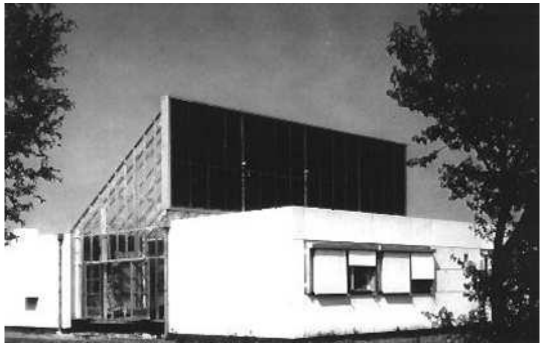


Figure 27 Image showing the DTH Zero-Energy House" (1975).

Source: korsgaard_dth_nullenergi.jpg (416×264) (passipedia.org)

the self-sufficient house, autonomous house, and greenhouse.

By subsequently implementing their "Green House" and "Autonomous House" theories to a house in Nottinghamshire, England, they resurrected sustainability in construction. The house was constructed using locally recycled resources like broken bricks, concrete blocks formed of waste ash from a nearby power plant, and bricks for the exterior walls heated with landfill gas from decomposing rubbish. From the perspective of energy and water supply, the house was seen as being relatively self-sufficient.

Several scientists gradually finished defining the sustainable development idea after the energy crisis. The building sector incorporated sustainability tenets, which were crucial in defining fresh design tactics. Later, structures that incorporated these ideas were affectionately referred to as "sustainable buildings," where the design has an orientation toward landscape integration and acceptance in the community. The term "sustainable building" evolved into a subset of the broader phrase "sustainable development". Federal research funding was given to Princeton University's Centre for Energy and Environmental Studies in 1974. The investigations of the impact of air exchange on building heat loss were started by the research team composed of Princeton House Doctors Ken Gadsby, Gautam Dutt, David Harrje, and Frank Sinden.

Top examples of actualized projects developed with energy efficiency in mind are the "Phillips Experimental House" (1975), "The DTH Zero-Energy House" (1975), "The Lo-Cal House" (1976), "The Saskatchewan Conservation House" (1976), see Figure 26 and "Leger House" (1977) see figure 27. The term "Zero-Energy House," which is now, first appears in the 1970s.

Figure 28 Image showing Wolfgang Feist and Bo Adamson created a sketch of the "Passive House. Source: passivhaus_kranichstein_sued.jpg (415×222) (passipedia.org)

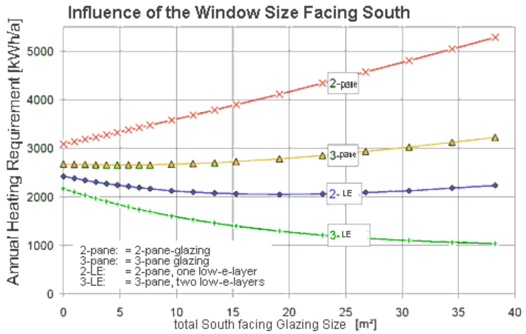


Figure 29 Image showing a graph of simulation results from the Passive House.

Source: fenster_ph_groesse.png (500×315) (passipedia.org)

The first "intelligent building" was made possible by early 1980s technical developments. Wolfang Feist advocates the idea of the "Low Energy House," and Hans Aek constructs a home with "Ultra-Low-Energy" characteristics. highly common. In the late 1980s, Wolfgang Feist and Bo Adamson created a sketch of the "Passive House" idea, which was influenced by the energy-efficient homes of the 1970s.

Beginning in the 1990s, the Passive House idea incorporated all the crucial design theories and algorithms. In Darmstadt, Germany, the first "Passive House Kranichstein" was constructed in 1991.

The first energy-autonomous home created by Germany's Fraunhofer Institute for Solar Energy in Freiburg was constructed in 1992. The house was able to meet its own needs without the aid of external energy sources because of excellent insulation and solar energy technologies.

A brand-new standard called Minergie was developed in 1994. Based on the concepts of Ruedi Kriesi and Heinz Uebersax, Minergie is a Swiss quality label for low-energy consumption buildings that was specifically established for new and renovated buildings. The first two Minergie homes were constructed in 1994. In 1998, Minergie was recognized as a standard. The Minergie Association labeled Minergie-P after three years. The Passive House standard's counterpart, Minergie-P, is more stringent than the original standard.

The first positive energy house, known as Heliotrope, opened for business in 1994. The architect Rolf Disch created the home that was constructed in Freiburg im Breisgau. In this home, energy production surpassed energy consumption for the first time. The technology used in the building drew its full energy supply from renewable resources.

Figure 30 Image showing Positive energy house, known as Heliotrope, opened for business in 1994.

Source: new-515.jpg (537×468) (inhabitat.com)

Figure 31 Image showing Positive energy house, known as Heliotrope, opened for business in 1994. Source: PlusEnergyHouse "Heliotrope" | sdg21

Based on his observations during the construction and operation of the first house erected in Darmstadt, W. Feist created the Passive House standard in 1995. The Passive House Institute, which was established in 1996 under the direction of F. Feist, began to promote the standard and outline specific requirements.

Since 1980, when several buildings increasingly integrated the control of diverse systems and equipment, the idea of an intelligent building had begun to take shape. Initially installed independently for each unit, automated systems in buildings eventually became complex enough to control several systems. The capacity to monitor and manage the power, heating, air conditioning, and security systems is now integrated into a single system. The use of monitoring and control via wireless networks and the internet has now been prompted by recent advances.

Wang (2010) identified four stages in the development of intelligent buildings: integrated single-function / dedicated systems from 1980 to 1985; integrated multifunction systems from 1985 to 1990; integrated systems at the building level from 1990 to 1995; computer-integrated buildings from 1995 to 2002; and enterprise network integrated systems from 2002 to the present. Table 2 shows the chronological history of energy efficient Buildings

Period	Location	Project/concept/equipment description
5500 B.C.	Dacia (Romania)	People used to construct "bordei" or "coliba" homes in the Carpathian region (E5500 B.C.). A portion or the entirety of this sort of home was constructed underground. The method proved particularly effective at maintaining a steady indoor temperature all through the year.
4000 B.C.	Persia (Iran)	An underground water canal (qanat) where evaporative cooling took place was utilized by Wind Towers (Bad qhir) to infuse fresh air from outside into the building.
3100 B.C.	Egypt	Construction of the walls with thick bricks as a thermal insulation to cool the indoor air
3100 B.C.	Egypt	Thermal insulation of the walls through an air cavity that separates two masonry walls
2650 B.C.	Egypt	Ceramic 'Tile" (Due to the thermal and acoustic insulation of pyramid routes, the phrase "to cover" is of Latin origin).
2500 B.C.	Egypt	cooling rooms by water evaporation.
1300 B.C.	Egypt	Houses with wind catchers ('Malqaf')
500 B.C.	Greece	Houses oriented to the south as usual rule – "Socratic Houses"
500 B.C.	Greece	Cavity walls often used by Greeks, a solution that Egyptians discovered earlier
400 B.C.	Roman Empire	Buildings commonly create the "Greenhouse Effect" by applying "mica" to the surface of the windows. The south-facing Heliocaminus has mica-coated windows that allow solar thermal energy to be trapped within. Burnt gases are circulated through floors with a lot of thermal mass using the "Hypocaust" heating system.
400 B.C.	Roman Empire, Middle East, Persia, Palestine	Solar chimneys are used to ventilate a home naturally. The chimney chamber is situated on the home's southern side. The ventilation air passively absorbs solar energy. The air is cooled as it circulates through an underground conduit thanks to the stack effect. Communities of Essenes were residing in improved caves, taking advantage of the ground's natural cooling properties throughout the summer.
50 A.D.	Roman Empire	Romans used the hot springs for baths and also to heat their homes
400 A.A.	France	Systems of water distribution from geothermal springs
600 A.D.	USA	Native Americans build houses in rocks oriented to the South (the practice was much older than the time of colonialism
900 A.D.	Iceland	In Iceland, turf houses were initially constructed between 800 and 900. The dwellings were constructed using natural materials including mud, stones, and turf strips. The 1700s wood problem forces Icelanders to revert to their old turf homes.
1200s	China	Traditional houses Toulu in Southern China. This type of buildings has properties encountered in passive houses. The heating and cooling systems were not necessary.
1500s	Italy	The first mechanical air cooler was created by Leonardo da Vinci and had a wheel that was partially submerged and was propelled by a water stream. The house was filled with air that had been cooled by the water evaporating process. He also created the original hygrometer, which measured humidity using a wool ball.
1760	Swiss	The first solar collectors were built by Horace de Saussure; the design is still in use today.
1800	Germany	William Herschel discovered Infrared radiation.
1855	Russia	The cast iron radiator, which is powered by hot water, was created by Franz San Galli as an inspiration from the designs of thermal radiators that were then in use. The radiator served as a prototype for modern hydronic radiator designs.
1865	USA	Thomas Stetson obtains a patent for double-layer windows that guarantee a more stable interior temperature.
1882	USA	The electric fan was created by Nikola Tesla, and later, an amazing way to cool the air inside buildings by placing ice in front of air currents was discovered, boosting comfort during the heat.
1883	Norway	The air sealing, thick walls, triple-pane glazing, and ventilation of Fridtjof Nansen's arctic ship "Fram" permit absence of a system for heating. According to reports, the "Frame" thermal principles of construction are remarkably close to those of a moder n "passive

		house."
1890s	Europe, North America	Scientists began looking into how well various systems insulated against heat and evaluated how well moisture moved through walls. Double-pane windows started to be used often.
1891	USA	The first commercial solar water heater was invented by Clarence Kemp, and it was made up of numerous 25-gallon cylindrical water tanks that were painted black and were housed inside a hot box. In 1896, Walter Rosen's residence makes use of it.
1902	USA	By circulating air via a system of cold or warm pipes, Willis Haviland Carrier invents the electric equipment for air conditioning that regulates temperature and humidity.
1904	USA	A psychrometric diagram of the wet air at constant pressure was designed by Willis Haviland Carrier.
1904	Italy	The first power plant using geothermal energy is built by Piero Ginori Conti.
1907	UK	iron pipes used for hydronic radiant floor heating
1920s	USA	Electric resistance heating is becoming quite common.
1923	France	Richard Mollier proposes using the h-x (enthalpy-humidity ratio) graphic to show the comfort zones.
1930	Germany	Due to its high insulating qualities and compactness, vacuum insulation panel (VIP), which is patented in Germany, is utilize d for structures as of the 1970s.
1933	USA	At the "1933 Century of Progress Exposition" in Chicago, George F. Keck builds the "House of Tomorrow," showcasing how glass walls can keep the internal air warm on clear winter days.
1935	USA	It is first made available for purchase as a compact room chiller that resembles a piece of furniture.
1937	Switzerland	The "Crittall" method of radiant heating and cooling through floor-mounted pipes is being proposed.
1939	USA	H. C. Hottel constructs Solar House #1 at MIT University using solar collectors and a water accumulator to show how the house may be heated in the winter. The MIT Solar House #7, which can generate more energy than it consumes, was built for the 2007 USA "Solar Decathlon," continuing the sequence of MIT houses.
1946	USA	The first ground-source geothermal heat pump was installed in Portland, Oregon's Commonwealth Building.
1946	USA	P-N Junction is discovered by Russell Ohl, and the first silicon solar cell that can generate electricity when exposed to light is produced and patented the same year.
1949	USA	In Dover, Massachusetts, Telkes and Raymond present a demonstration of the thermal storage in a phase-changing substance (Glauber Salt NaSO4.10H2O) that will be typical in 1973 for the construction of passive solar-heated walls.
1950	USA	An air-to-air heat exchanger with heat recovery was employed by Giese and Downing for an animal shelter. The consequence was a significant decrease in the amount of heat lost through ventilation in the cold.
1950	USA	First radiant ceiling panel heating system
1953	Canada	Hutcheon thought about how airtight the structures were in light of his concern for preventing moisture in the walls. Twenty years later, there is still a link between the airtightness and less heat loss.
1955	USA	Bliss builds a house on a rock bed in the desert of Arizona that uses thermal storage to store solar energy.
1960s	USA	With growing computer processing, there are established ways for estimating the energy use in buildings based on weather data. Later, advanced techniques like Degree-Day, Bin, Modified Bin, etc. were created.
1967	USA	The most popular comfort model now is one that Fanger proposes. Several types of heat transmission body -environment and the individual's perception of comfort are taken into account by statistical algorithms.
1970s	USA	The term "sustainability" appears in economics. Edward Barbier (1987) uses for the first time the notion of "sustainable development". The "Brundtland Report" of the United Nations provides a definition that takes into account the demands of the present without compromising the needs and concerns of future generations. A manual on "sustainable construction" is presented in the 1992 issue

		"Environmental Building News."
1972	France	Felix Trombe constructs a glass-covered wall with an outside surface that separates an air space; this traps solar thermal energy. A similar form of wall was first described and patent by American Edward Morse in 1881.
1973	World	Oil crisis brought on by OPEC's Arab members and a significant spike in oil prices Building energy efficiency has become more popular as a result of this incident.
1975	UK	"The Autonomous House," a technical manual for developing housing options that are energy-self-sufficient, environmentally beneficial, somewhat simple to maintain, and have a traditional appearance, is published by Brenda and Robert Vale. They also define the concept of a "Green House"
1975	Germany	The "Phillips Experimental House," a super-insulated experimental home outfitted with ground heat exchangers, controlled ventilation, solar, and heat pump technologies, is built by Horster and Steinmuller in Aachen.
1975	Denmark	At the Technical University of Denmark, Esbensen and Korsgaard build the "DTH zero-energy house" and popularize the phrase "Zero Energy House." Specifications: solar collectors with water storage tank; super-insulated (12–16 mm thickness); air to air heat exchanger (80% efficiency); double panel windows. Air infiltration in the envelope was taken into account, but at sub-evaluated values of 0.03...0.15 h1.
1976	USA	At the University of Illinois, Wayne Schick builds "Lo-Cal House" (Low Calorie House). Specifications: air barrier, double walls, triple panel windows, and super-insulation. The idea of "super insulation," is developed further which William Shurcliff further developed in articles published in 1980.
1977	Sweden	Researchers from Sweden measure the airtightness of buildings using the "Blower Window Test." The "Blower Door Test," which is more useful, is used to improve the test procedure in the USA. According to Gautam Dutt, air leakage is the primary reason why building heat losses are 3–7 times higher than those predicted by the computation.
1977	Canada	The Saskatchewan Conservation House was built by Harold Orr, Robert Besant, Rob Dumont, and Rob Dumont [25–27]. Specifications: solar collectors, triple pane windows, heat recovery ventilation, air tightness (0.8 h1 at 50 Pa), and excellent insulation. Rob Dumont compares passive design to active design and uses the phrase "low-energy dwelling."
1977	USA	In Pepperell, Massachusetts, Eugene Leger builds the "Leger House". Specifications: air to air heat exchanger, excellent insulation, and air tightness.
1979	USA	In Pepperell, Massachusetts, Eugene Leger builds the "Leger House" [18]. Specifications: air to air heat exchanger, excellent insulation, and air tightness.
1980	USA	The beginning of shaping the intelligent building concept
1985	Sweden	In Ingolstadt-Halmstadt, Hans Aek builds a "Super-Low-Energy House" with a heating load of 30 kW h/m2/y. Specifications: airtightness, high insulation, and mechanical ventilation using an air-to-air heat exchanger.
1987	Germany	The first low-energy building in Germany, "Schrecksbach House," was built in 1987 and was designed by Manfred Such.
1988	Germany, Sweden	Based on performances of "Schrecksbach House," Wolfgang Feist promotes the idea of "Low Energy House". Bo Adamson (Sweden) and Wolfgang Feist (Germany) drew the blueprints for the energy-efficient homes from North America as inspiration for their "Passive House" design.
1990	Germany	The architects Bott, Ridder, and Westermeyer who built Darmstadt's "Kranichstein Passive House" brought Wolfgang Feist's ideas to life. Specifications: 80% efficiency mechanical ventilation with heat recovery via air-to-air heat exchanger and pre-circulation of the air through an embedded tube in the ground. Highly insulated walls (lateral walls 275 mm, roof 450 mm, interim roof 250 mm).
1993	UK	Brenda and Robert Vale build the "Autonomous House," a greenhouse that can generate a sizable percentage of the required energy. Specifics: PV panels, recyclable materials for the walls, etc.

1994	Germany	An "auto-sufficient" or "autarchic" home is built by Fraunhofer Institut for Solar Energy Systems. The house is not wired into the general power system. PV panels generate the electricity, which is then stored in conventional acid-based batteries. Details include solar collectors, an earth-to-air heat exchanger, and humidification and dehumidification equipment. The home is a prototype for the "Plus-Energy House" concept that will be introduced later in 1996 and produces five times as much electrical energy as it consumes.
1994	Germany	In Freiburg, Rolph Disch constructs Heliotrope, a machine that can generate four to six times as much energy as is required internally while emitting no CO2. Details include a solar tracking system for the PV panels, walls made of phase-changing materials, and walls insulated by internal vacuum space.
1995	Germany	Wolfgang Feist defines Passivhaus Standard <15 kW h/m2/y, Airtightness Pressure Test n50r0.6 h/1, Primary energy demand (for all energy services) <120kW/m^2/y
1996	Germany	Foundation of PassivHaus Institut by W. Feist in order to promote Passivhaus Standard
2000s	USA, Europe	Infrared Plasm Heating Panels are commercialized
2004	Germany	The Plusenergiehauss-compliant solar city Solarsiedlung am Schlierberg was created by architect Rolph Disch. It includes Sonnenschiff (Solar ship), the first commercial building to use positive energy, which is networked with nearby structures that have solar panels put on their roofs. It is an independent city.

Table 1 showing the chronological history of Energy Efficient Buildings;

Source: Author modified, 2023

2.2 Energy-Efficient Buildings in the 20th Century

Figure 32 Image showing Chandigarh, India by Arch. Le Corbusier.
Source: 01_Palace-of-the-Assembly_05.jpg (1280×853) (adsttc.com)

It is vital to study the advancements and changes in the field of energy activity in buildings (functionally independent) as well as the social events that served as the driving force behind the alterations if one is to comprehend the previous century. It is hard to think that advancements in the previous century occurred independently of social and social realities or events.

The Industrial Revolution, the utilization of steam power, the introduction of electric energy through the grid, the introduction of mass production into many spheres of life, and the demands made by new space requirements are some of the most significant advancements of the 19th century. The key ideas in energy efficiency for buildings before the 20th century were passive design systems and climatic design. In this situation, factors including location, orientation, building shape, shading from nearby structures and the landscape, building envelope, heat retention, moisture movement, and cooling based on natural ventilation could be used to promote energy efficiency and comfort. The systems employed were an extension or reflection of earlier experiences.

Figure 33 Image showing Bahaus Building by Walter Gropius architect.
Source: 1920px-Bauhaus_Dessau_2018.jpg (1920×1152) (wikimedia.org)

At the beginning of the 20th century, techniques and inventions that would eventually result in the creation of many systems utilized in modern structures and energy efficiency began to take shape. The emergence of electrically operated air conditioning units, the use of innovative building supplies like reinforced steel and concrete in construction processes, and the emergence of the elevator, which pushed the construction of multi-story buildings, could be seen as some of the most significant developments in the construction method during this time, including World War I. The initial attempts to utilize integrated air conditioning and heating systems in buildings occurred around this time, which increased the amount of energy required to construct new buildings and operate the buildings.

Figure 34 Image showing Flatiron Building in the USA among the first buildings to employ HVAC systems. Source: OIP.kA-N9XlXPIRicwKypAN1xwHaLI (466×700) (bing.com)

Due to the global industrial revolution, which took place in the second quarter of the 20th century, mass production increased practically everywhere, including the construction industry. Modernist architectural examples can be found.

Examples of climate-independent design can be seen in the development of heating, ventilation, and air conditioning (HVAC) systems and their integration with the buildings. After World War II, renewal movements in Europe started to remove the remnants of demolition, nuclear energy was created, and at the start of the 1950s, the idea of optimization emerged intending to make the best use of available resources. At this time, the first studies on the use of geothermal heat pumps and solar energy were initiated. This period is characterized by new technology, a growing population, urbanization, a shortage of land in cities, and the creation of tall buildings. While increasing the amount of energy utilized in the buildings, transparent and permeable surfaces employed on the structures represent the architectural vocabulary of the time. The foundation of the European Union, the development of space technology in the 1960s and its application to daily life, the introduction of nuclear energy, the rise in population and dependence on energy are only a few of the major social events that can be enumerated (Ionescu et al., 2015).

A significant shift in building energy-efficient design occurred as a result of the 1973 oil crisis. Societies have to come up with diverse solutions as a result of the abrupt rise in energy prices and the challenges of accessing energy supplies. Important developments during this time include the understanding of the significance of energy efficiency in buildings, the return to passive design principles (Commission of EU, 1991), and the development of computers. An energy-saving consciousness appears to be growing throughout this time. It is advised to use energy resources as efficiently as possible.

The term "sustainability" was first used publicly in 1987 with the presentation of the Brundtland Report (World Commission on Environment and Development-WCED, 1987) titled "Our Common Future" at the United Nations. The significance, necessity, and elements of sustainable development are discussed in this thesis. As a result, the three primary aspects of sustainability—economic, environmental, and sociocultural—are stressed. The fact that this report mentions both the environmental impact and the economic impact is among its most crucial features. There is now discussion surrounding how energy resources affect the environment.

Figure 35 Image of Guaranty Building, a glass building in the USA by Architect Lois Sullivan. Source: 9e6e717097eb82ce6ac60f9e84bc9d52--louis-sullivan-adler.jpg (736×907) (pinimg.com)

However, the significance of statutory rules is also recognized, as is the significance of monitoring and assessing consumption levels and formulating plans based on statistical information. High-tech architectural structures started to be constructed over time. Integrated design teams have started to develop creative ideas for energy efficiency in the construction of new structures. In the design sector, there are several systems that are implemented in conjunction with architects, engineers, specialists, and consultants. Over this time, energy efficiency has also increased in importance, as has energy management.

In the 1990s, the ozone layer began to deteriorate further, the Kyoto Agreement was ratified in the year 1997, and environmental impact emerged as a contentious issue. The 1990s began with several new developments, including the founding of the European Union, a globalization debate, the formation of multiple business models, and the introduction of personal computers as a kind of computer technology. Discussions on the environmental effect of buildings, their energy use, and the wide range of energy resources they use have all started. Studies have been done on adapting renewable energy sources for usage in buildings.

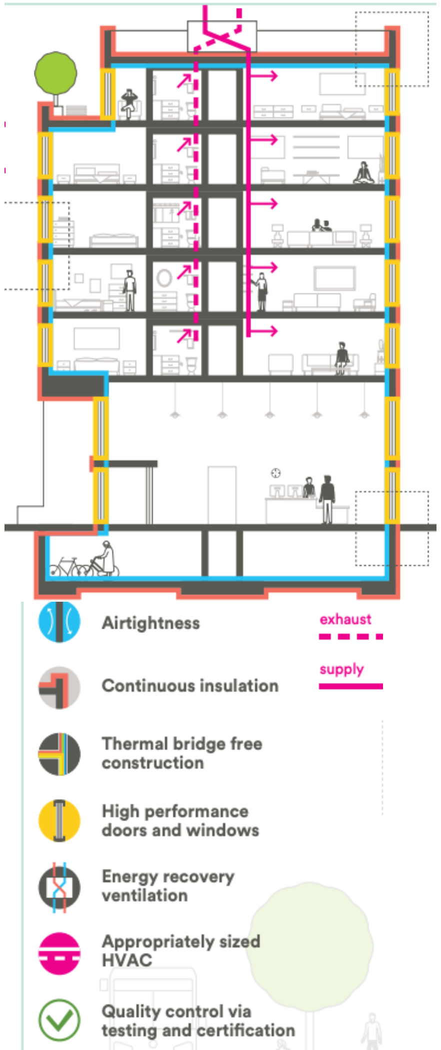


Figure 36 Image showing Passive House Principles.

Source: Passive House standards proving their worth in multifamily sector.png (1091×594) (bdcnetwork.com)

Integrated design, which foresees the participation of all design stakeholders for efficient use of energy, has grown in favour. Several detailed levels of modelling tools, incorporating life cycle evaluation, have also been employed. Passive home standards have also been developed. Along with all of these, the concept of green buildings and energy efficiency have also been put out. This implies that environmentally friendly buildings are constructed using an approach that consumes the least number of resources on Earth, uses the least quantity of energy to make them, is least harmful to the atmosphere, and is concentrated on utilizing sources of renewable energy and producing the lowest amount of waste when in use.

The concept of a computerized, intelligent building also began to take hold around this time. The early 1970s idea of Reuse, Recycle, and Reduce, or 3R, received increasing prominence at this time and was also included in the architectural construction and design procedures. Thanks to the methods that have evolved in tandem with the concept of a "green building," buildings may now be rated following green building standards. This results in different degrees of certification for buildings (Celebi et al. 2008). During the start of the new millennium, standards and, as a result, grading and assessment systems, came to be widely used. In 2002, and again in 2010, the European Union set energy performance rules that apply to buildings.

By these instructions, member states must create the standards, pick the rules for their application, and portray them as universal norms while taking into consideration their unique local circumstances. Both the variety of green building grading systems and the rate of uptake in the building sector have increased. requirements have been set for monitoring and controlling energy efficiency, and the requirements have been raised throughout time.

Documents detailing energy performance have been designated. While promoting the adoption of renewable energy, greater efforts are being made to reduce the usage of fossil fuels. There have also been studies on potential situations and improvements that may be made to the stock of existing structures. It is now generally accepted that designing shared living spaces rather than buildings as a whole will ensure energy efficiency.

All waste generated by buildings, toxic gas emissions, and a reduction in carbon emissions are now taken into account alongside energy efficiency. All embodied energy must be considered to reduce the amount of energy used in the production of all building materials and components.

The 2010 European Union Renewable Energy Directive established the definitions of "net zero emissions" and "almost zero energy" in terms of requirements. Buildings are therefore designed to utilize and generate as little energy as possible, and dangerous gas emissions are supposed to be reduced. By 2018, every new building being built across all member states are expected to be subject to this guideline. The attainment of cost-effective construction techniques is nonetheless a requirement of the stated objectives. The construction of high-performance buildings is one of the goals of energy efficiency at the moment. While it is clear that the quantity of energy generated using petroleum and coal is dropping, the approach based on sources of clean energy is expanding nowadays. The well-known energy simulation models may be used more effectively to establish plans for consumption. The 2020 energy objectives include a 20% reduction in energy consumption, a 20% reduction in emissions of greenhouse gases, and a twenty percent rise in the usage of renewable energy. Buildings with positive energy are commonly referred to as constructions that produce more energy than they need.

Timeline	Architectural Movement	Social Events	Effects Social Events	Energy efficiency in Buildings
Before 20th Century	Vernacular Architecture	Industrial Revolution	Steam-powered electricity supplied through a grid Specialization, mass manufacturing, and a requirement for additional places	Past experience with passive systems
First quarter of the 20th Century	Modernism Futurism	First world war Use of elevator New building materials (reinforced concrete, steel, the invention of AC	Initial stages for combined AC, heating, and cooling.	adaptability of new systems, climate-independent design
Second and third 20th century	Modernism	2nd world war Nuclear energy Space Technology Establishment of European Economic Community	Mass manufacturing following the Second World War The concept of optimization Using solar energy: the basics Geothermal usage basics Heat pump technology fundamentals	Integration of systems
Twentieth Century 1970-1980	Post-modernism	oil crises of 1973	Returning to the principles of climate-based design principles of passive homes The evolution and use of computer technology	Conservation of energy
Twentieth Century 1980-1990	High-tech	Destruction of ozone layer 1987 Bruntland report The term "Sustainability" Developments of personal computers	Models of global development Sunny homes principles of passive design environmental awareness	Energy conservation and management
Twentieth Century 1990-2000	Deconstruction	Kyoto agreement Establishment of European Union (EU) Green building certification systems	Environmental awareness Passive Household norms green structures Analyses of life cycles software for energy-based simulations Integrated planning the use of renewable energy Smart structures	many sources of energy Renewable energy sources' effectiveness
21st Century 2000-2010	Sustainability	2002, 2010 EU Energy directives Energy Performance Building Directives (EPBD)	methods for green building certification certifications for energy efficiency the use of renewable energy updated energy efficiency benchmarks Future climate change scenarios	Standards emissions reduction usage of less energy lowering carbon footprint
21st Century 2010-2020	Sustainability	2010 EU Energy directive Paris Agreement	High-performance structures Buildings that are net zero or almost zero	use of less energy renewable energy
21st Century 2020-			Positive energy	Energy generation

Table 2 shows social activities and energy efficiency initiatives over the last 100 years.

Source: Author modified, 2023

2.3 Designing Energy-Efficient Buildings Considering the Life Cycle of a Building Project

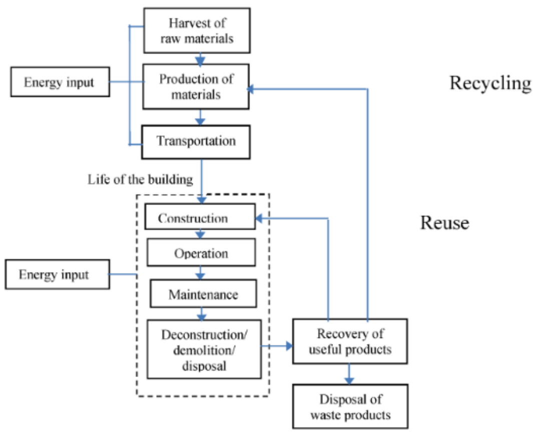


Figure 37 Image showing energy input during the life of a building.

Source; Author Modified, 2023

Every phase of a building's life cycle involves varied degrees and purposes for energy consumption. Energy is utilized for material production, distribution, and construction "at least five times" as needed in the quantity of energy used and operational stages for a building with a 50-year lifespan. Heating, refrigeration, air circulation, and artificial lighting already consume a large amount of energy (between 35 and 60%).

Most buildings are expected to last over fifty years if a person lives a long period, therefore energy-efficient technologies can drastically lower energy use. Focusing on the usage and operation phase is essential, even only for the time being. Applications to lower building energy use exist in a variety of forms. Energy usage throughout each step of construction is considered while analysing the building life cycle. In this sense, we must be mindful of the life cycle that comprises buildings. The three main stages of a building's life cycle are pre-building, construction, and post-construction. These phases include specific processes. The preliminary building process comprises choosing the ideal location, arranging the area effectively, creating the building shape, and planning the site. In addition, it calls for the choice of energy-efficient construction materials, the creation of an energy-efficient landscape, the acquisition of raw materials for the production of the building materials, and their transportation. This phase includes the development and operation of the building. The post-construction phase is the time immediately after the building has stopped being used. During this stage, the structure will be demolished, recycled, and thoroughly cleaned.

There are different methods of ensuring that buildings are energy efficient depending on the lifecycle phases:

2.3.1 Energy-efficient design techniques during the prebuilding phase of a project:

Initial building activities include identifying a construction site, planning the structure, selecting building materials, sourcing raw materials for the materials, manufacturing them, and transporting them. The strategies with substantial energy savings in the building life cycle have been described in these processes, including appropriate site selection, planning the location, building form, building plan, and suitable space organization, as well as the design of the envelope of the building, the selection of building material, landscaping design, and sequentially utilizing energy sources that are renewable. These strategies are discussed below:

• Appropriate site selection	• The layout of the building and proper space organization	• Energy-efficient landscape design
• Site planning	• Building envelope	• Use of renewable energy resources: a. Employing passive methods to use renewable energy sources b. Employing active techniques to use renewable energy resources
• Building form	• Choosing energy-efficient building materials	

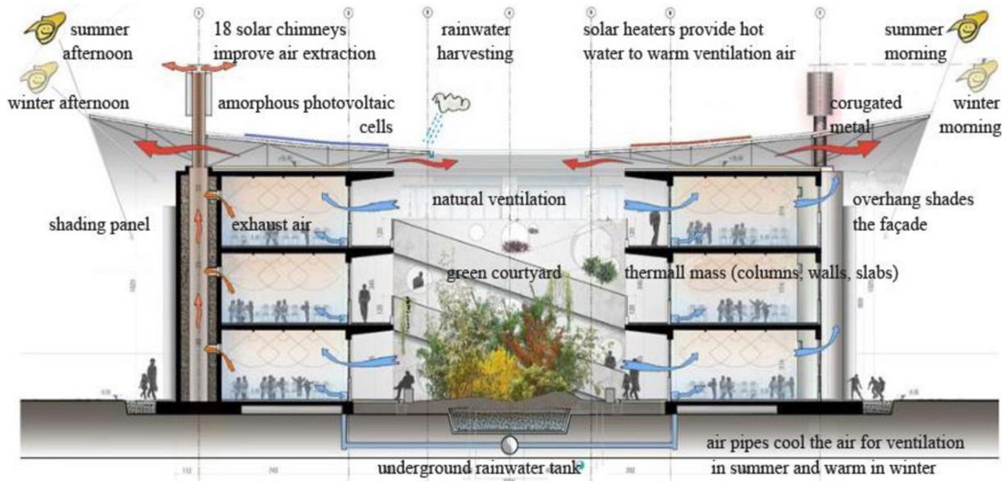


Figure 38 Image demonstrating some of the design techniques in Bioclimatic architecture, of Kuwait School in Khan Younis.

Source: Figure 5 from Bioclimatic architecture as an opportunity for developing countries | Semantic Scholar

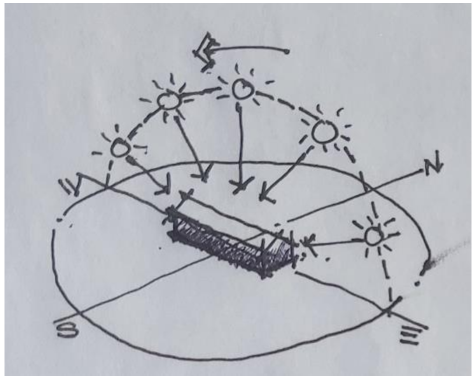


Figure 39 Image showing orientation according to the sun.
Source: Author modified, 2023

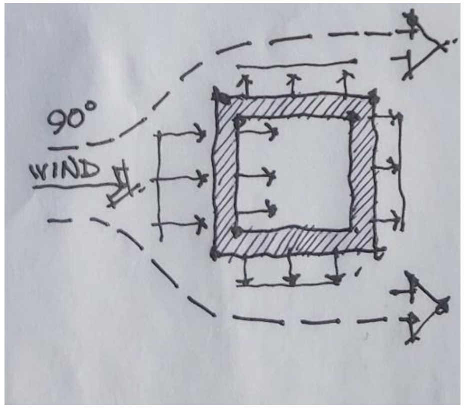


Figure 40 Image showing orientation according to the wind.
Source: Author modified, 2023

i. *Appropriate site selection*: the location of a building affects the microclimate conditions, which have a substantial impact on the building's energy efficiency. These conditions include climatic factors like solar radiation, air temperature, air circulation, and humidity, all of which have an impact on energy costs.

One of the most crucial design factors that affect the amount of solar radiation and the speed of air circulation around buildings is the location of the building and the distance between neighbouring buildings. The location of the building in the area should be chosen to take advantage of and protect against renewable energy sources like the sun and wind.

ii. *Site planning*: A key architectural element that affects the way solar energy, the direction of wind, and speed are exploited in the setting of an artificial setting is the spacing between structures. During the design stage, structures should be viewed in tandem with their environment.

The distances among buildings have a considerable influence on a building's energy efficiency throughout its use phase. The position of a building inside the shadowed region of neighbouring structures affects how well solar rays are used, which raises energy consumption.

To make use of solar radiation, buildings must be not less than as tall as the highest structure's shadow height.

A building's energy efficiency is also impacted by the placement and distance of other structures, which alter the direction and speed of the wind in that area.

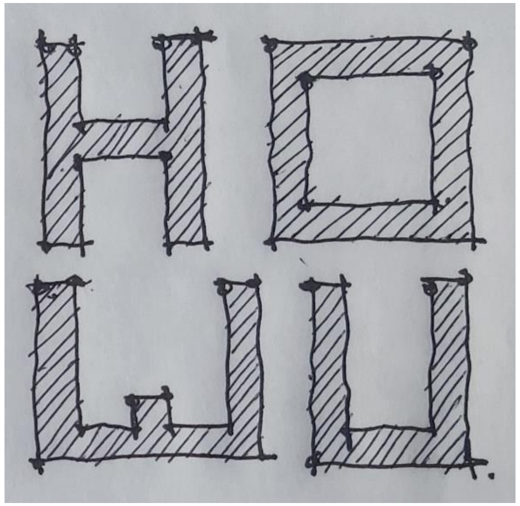


Figure 41 Image of building plans with good access to natural light and with good potential for natural ventilation.
Source; Author Modified, 2023

The ratio of the solar radiation gain of a building's sides is influenced by its orientation, which also has an impact on the building's overall solar radiation gain. Additionally, the side of buildings influences wind speed, which in turn influences the likelihood of natural ventilation as well as the rate of heat loss due to convection and air shortage. Buildings must therefore be orientated to avoid or profit from the sun and wind depending on the weather and the needs of that place.

iii. *Building form:* The percentage of solar radiation gain of a building's facades is influenced by its orientation, which also has an impact on the building's overall solar radiation gain. Additionally, the side of buildings influences wind speed, which in turn influences the likelihood of natural ventilation as well as the rate of heat loss due to convection and air shortage. Buildings must therefore be orientated to avoid or profit from the sun and wind depending on the weather and the needs of that place.

Building characteristics like its form, volume surface rate, and frontal motions all have an impact on how energy-efficient it is. The geometrical shape and the building's energy efficiency are directly related.

The various climatic conditions influence the significance of the shape of the building. Compact forms that reduce heat loss should be used in areas with cold climates. Compact designs and use of courtyards, reduce heat gain and aid to offer sheltered and cooler dwelling spaces, should be employed in hot, dry climate regions. Long and narrow forms with the long facade towards the direction of the prevailing wind allow for the most cross-ventilation in hot, humid regions. Compact forms should be employed in mild climates because they are more adaptable than designs used in cold climates.

iv. Building layout and appropriate space organization: The shape of a building is critical to its performance in its location and climate. Compact forms should be employed in cold-temperature areas to reduce heat loss. Compact shapes and courtyards should be employed in hot, dry climate zones to reduce heat gain and assist create shaded, cool living spaces. Long and thin forms with the long side facing the prevailing wind direction allow for the most cross-ventilation in hot and humid climates. Compact forms, which are more flexible than the forms utilized in cold-temperature regions, should be employed in warm climates. The internal organization of the design can lower the energy requirements of buildings. The need for heating energy can be decreased by utilizing the sun's radiation to its fullest potential. These common areas need more heating, whereas rooms with a reduced heating requirement, such as the pantry, bathroom, and toilet, can be used as buffer areas to lessen heat transmission to the outside by positioning these in locations where heat is lost.

If sunrooms are placed on south-facing building facades, they can help with energy saving and building heating by storing solar radiation.

v. Stratification can conduct zoning in a building design dependent on the buffer zone, sanitary spaces, level of noise, lighting level, and heating requirement. Therefore, places with heavy traffic and those that are used all day should face south. It is possible to raise mutual air motion by carefully designing the zone for thermal and indoor space of settlement. By using excessive dividing components and doing in-depth planning, air circulation in the environment may be hampered.

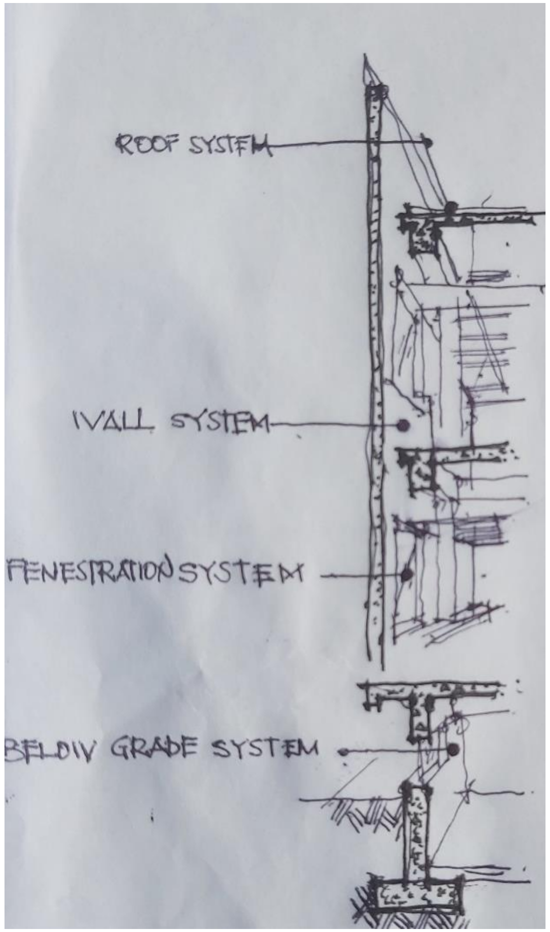


Figure 42 Image showing a building envelope.

Source: Author Modified, 2023

i. Building envelope: The term "building envelope" refers to the materials, such as the walls, floors, ceilings, windows, and doors, that separate a structure's conditioned interior from its outside while yet enabling thermal energy to pass between the two. As both an indoor and an outdoor reagent, it plays a significant role in energy use. While the cost of building an envelope makes up 15–40% of the total cost of construction, it accounts for 60% of life cycle costs, notably energy costs. The outside covering of a structure acts as an aperture between interior and external environments to control the infiltration of the atmosphere, heat, cold, and light.

Heat gain in the hottest months and heat loss in the coldest months should be reduced by the building envelope. The exterior and interior structural features of building elements that comprise the building's outside shell, such as walls, windows, floors, and doors, have a significant impact on how much energy the building consumes.

Below is a description of the building's component's energy-saving attributes. Figure 42 shows the image illustrating an example of a building envelope.

Exterior walls: The construction components that make up outside walls, and qualities of the layers of building elements and their arrangement, are related to their thermal and massive properties. Heat gain and loss will be minimized by massive, well-isolated walls with a high thermal-storing capacity.

Depending upon the climatic zone characteristics, the creation of external surfaces that can receive solar radiation or be protected from direct radiation in terms of heat gain should be managed.

When dark, high-density building materials are used in sun-exposed regions, the wall-to-window percentage should not exceed 15% to save as much sunshine as possible throughout the winter.

Roofs: Commercial and institutional buildings typically have flat roofs, and the insulation may be suspended from the ceiling. In gabled roof buildings when the attic is not utilized, the insulation is often located in the ceiling. The shape, material, gradient, direction, colour, and insulating characteristics of the roof all have an impact on the thermal performance of the buildings. Roofs must consequently be built to accommodate climatic conditions.

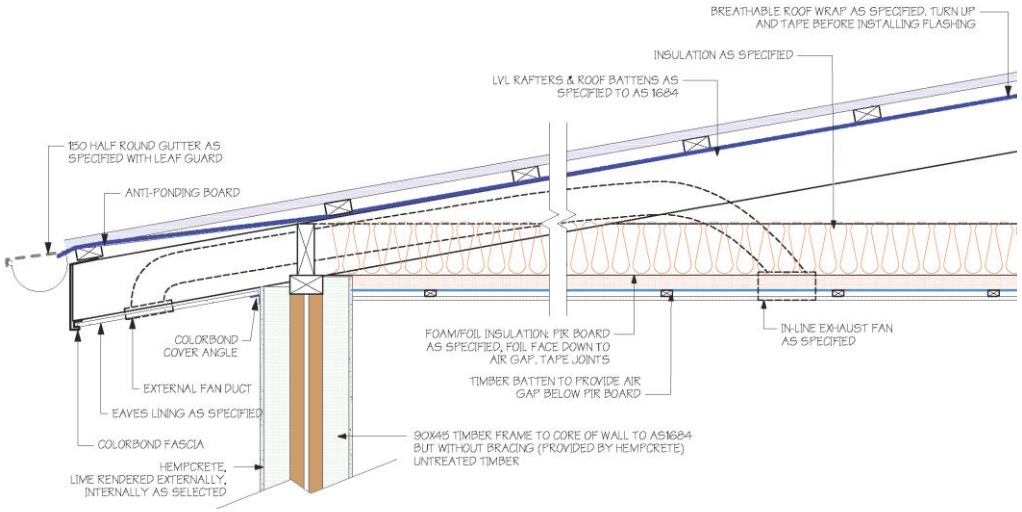


Figure 43 Image showing Insulation for a Pitched roof.

Source: PD_Insulation_5.png (2183×1208) (yourhome.gov.au)

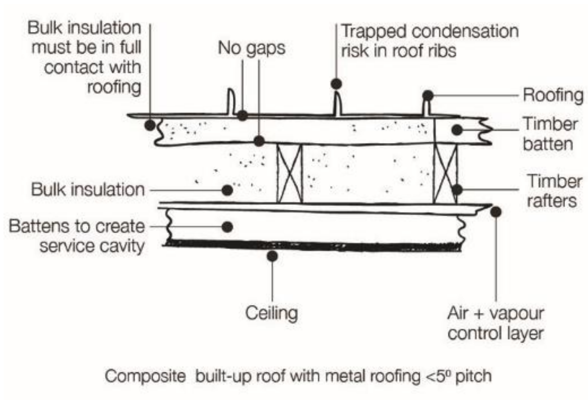


Figure 44 Image showing Insulation of a Flat Roof.

Source: PD_Insulation_9 LowRes.jpg (750×504) (yourhome.gov.au)

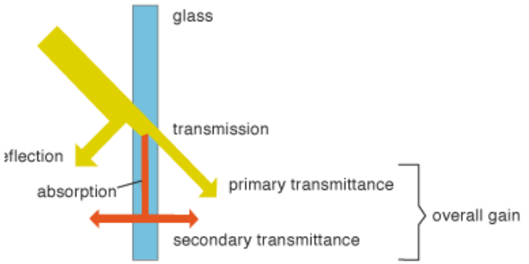


Figure 45 Image showing transmission of heat through the glass.

Source: solar-gain.png (451×210) (greenspec.co.uk)

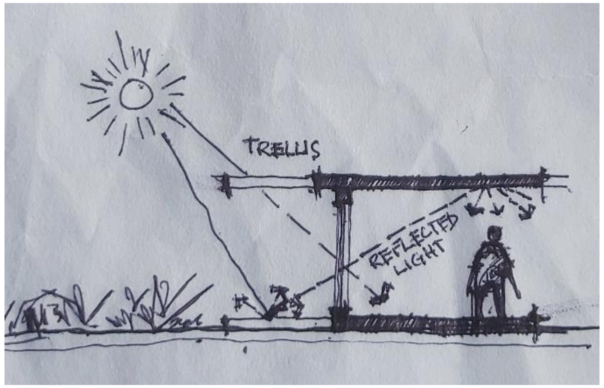


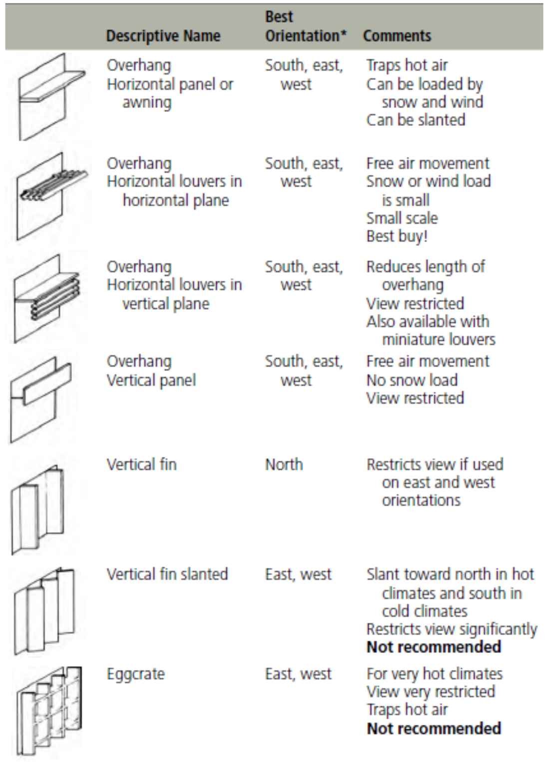
Figure 46 Image showing quality daylight by blocking direct sunlight while encouraging reflected sunlight. Source: Author Modified, 2023

Roof thermal insulation qualities, gradient, and facade should be chosen in accordance with the climatic character. In temperate dry, temperate humid, and cold temperature zones, well-isolated gradient roofs should be employed. Flat roofs should be utilized in hot and dry climate zones to reduce the impacts of solar radiation; elevated or sloping roof configurations should be used in hot and humid climate zones with airflow.

Windows: Windows have an impact on a building's energy efficiency through heat input or loss, natural ventilation, and lighting. In terms of heat gain, the south is the best direction, followed by the east and the west. A large window increases daylight while reducing the demand for artificial lighting.

In order to provide enough outside lighting, windows should be of the right size. For instance, the window's size should occupy at least fifteen percent of the room's floor space. When choosing the openness of rates for the building envelope, it is important to understand the climate zone in which the project is situated. In hot and dry climate zones, small and limited openings should be used since protection from the sun's rays and the wind is the main priority. In hot, humid areas, large apertures should be utilized with the necessary safety precautions to improve indoor air circulation. Small and only a few windows should be used in cold climatic zones to prevent heat losses from windows.

To take advantage of the benefits of solar radiation, glazing on the southern façade must be kept open more frequently compared to those on other elevations. Openings should provide for appropriate air circulation in temperate areas. Windows offer several essential services including airflow, daylight, as well as entry to the natural world with little influence on building expenses.



Descriptive Name	Best Orientation*	Comments
Overhang Horizontal panel or awning	South, east, west	Traps hot air Can be loaded by snow and wind Can be slanted
Overhang Horizontal louvers in horizontal plane	South, east, west	Free air movement Snow or wind load is small Small scale Best buy!
Overhang Horizontal louvers in vertical plane	South, east, west	Reduces length of overhang View restricted Also available with miniature louvers
Overhang Vertical panel	South, east, west	Free air movement No snow load View restricted
Vertical fin	North	Restricts view if used on east and west orientations
Vertical fin slanted	East, west	Slant toward north in hot climates and south in cold climates Restricts view significantly **Not recommended**
Eggcrate	East, west	For very hot climates View very restricted Traps hot air **Not recommended**

Figure 47 Image showing different ways of sun-shading windows.

Source: Heating, Cooling, Lighting, Norbert Lechner

The placement of window openings toward the north façade should not be favoured in climates with harsh winters since the heat gained from the sun is insufficient to warrant consideration, air penetrations rise because winter winds typically blow from the north, and heat losses subsequently increase.

It is possible to obtain an appropriate amount of solar gain through the apertures positioned to the east and west elevations, even though it is lower in winter than the southern facade. We run the danger of overheating since the summer sun rises horizontally in both the morning and the afternoon, making it difficult to fill in these spaces. However, windows that are facing south can benefit from the practically constant horizontal sunbeams in the winter and are easily protected from more intense vertical solar rays in the summer. Due to all of these features, windows located on the southern face are typically utilized to passively absorb solar energy.

However, applications for nocturnal isolation are required to prevent thermal losses that might happen after sunset. Shutters, roller blinds, or jalousies fixed from the inside or outside are some examples of these separation features. Or, losses should be minimized by at the very least close the curtains completely. Eaves, sunshades, or curtains can readily shield windows throughout the heat.

High-performance glass with the best thermal and light transmittance coefficient for the desired qualities should be used in the front, depending on the environment, the direction of the sun, and the intended use of the building. Energy efficiency is enhanced by separated joineries, low-emissivity coated glass, argon or krypton-filled double glazing, and airtight finishing and composition.

ii. Choosing energy-efficient building materials: Building materials should have components that are energy-efficient throughout both the manufacturing and consumption processes. Below are explanations of the characteristics of construction materials that save energy.

Local material: Building materials' affordability and energy efficiency are impacted by the amount of energy required to transport them to construction sites, which is a sizeable fraction of the overall energy used in construction. As a result, if the building supplies are manufactured locally and as close to the construction site as is practical, less transportation energy will be used, which will significantly improve the structure's environmental performance.

Recycled materials: Many construction materials take a sizable amount of energy to produce. The useful life of the unprocessed products is greatly extended and the amount of energy used is decreased when recycled sources are used in place of non-newly treated sources for the manufacturing of construction materials. Recycling is essential to reducing the quantity of energy which is incorporated in a construction. When compared to materials manufactured from natural resources, employing recycled metal, for instance, leads considerable reductions in energy consumption within a rate of 40 and 90%. Less-energy-intensive products employed on this construction site include: The way the job site is run, the need for power, and the usage of equipment, heating, or light of influence on the amount of energy consumed there.

Employing durable building materials: Using sturdy building materials enables the construction of stronger, longer-lasting buildings. This delays or eliminates the need for material substitution or upkeep due to wear and tear. This method makes it feasible to create the materials required for maintenance or renewal without requiring energy. High-capacity building materials for thermal insulation: By choosing construction materials with strong thermal insulation capabilities, the amount of energy that a building consumes during its usage phase may be decreased. materials for insulation that are translucent and opaque are examples.

iii. *Energy-efficient landscaping design:* This is feasible to reduce energy costs associated with heating and cooling throughout the hot and cold seasons by 30% through correct and mindful energy-protected landscape design. Via vapor movement, the outside and grassy ground surfaces have a

cooling effect. Materials like asphalt that store heat continue to radiate heat into the night and expand heat after the sun sets. Among the precautions to be taken to limit the amount spent on cooling are using materials that store heat and reflect light little or shielding them from direct sunlight.

The energy-saving landscape techniques vary by region. As seen in the list below, these landscaping techniques are sorted by region and relevance.

Via vapor transportation, the outside and grassy ground surfaces have a cooling effect. Materials like asphalt that store heat continue to radiate heat into the night and expand heat after the sun sets. Among the precautions to be taken in order to limit the amount spent on cooling are using materials that store heat and reflect light little or protect them from direct sunlight. The energy-saving landscape techniques vary by region.

A. *Use of renewable energy resources:* All living things on earth can utilize renewable energy sources, such as the wind, sun, biogas, biomass, geothermal energy, hydroelectricity, ocean thermal energy, ocean and wave currents, which have been identified as endless due to their ongoing replenishment. You can use both passive and active strategies to take advantage of renewable energy sources.

I. Employing passive methods to use renewable energy sources:

a. Passive heating Systems for solar heating that are passive are categorized based on the connections between the solar energy system and the building. There are three types of passive solar heating systems: straight gain, indirect gain, and isolated gain. Heat is gathered and stored by building elements (such as openings, walls, floors, etc.) in the solar thermal passive heating system before being transferred throughout the interior.

b. *Direct gain systems*: Windows that face a gain Winter sunlight can penetrate the space that is occupied directly in passive solar buildings. These solar gains can be preserved in thermal mass to aid with future heating needs or contribute to meeting a portion of the building's present heating needs. The following characteristics characterize most of direct gain buildings:

Two factors that reduce temperature variations include thermal mass inside the insulating envelope as well as big, south-facing glazing (for the northern hemisphere).

The calculated overhang above the glazing on the south facade or another shading method on the glass in the summer while allowing for lower angle winter insolation; a technique for deducing heat loss at night: Sunlight is directly admitted to the inside of a direct gain structure through glazing. It hits large interior surfaces (usually brick walls and concrete floors), is absorbed, and then transforms into heat. Instantaneously, some of the heat from the surfaces is returned to the room's interior. The remainder of the heat is channelled to the thermal wall, that slowly warms up; further into the night, this heat is expelled back into the object's interior.

c. *Indirect gain systems*: The thermal storage of an indirect gain passive solar system is located between the building's exterior and interior. Heat is collected and stored in the exterior wall or roof of a building (using water, brick, or concrete), then distributed within.

d. *Isolated gain passive systems*: this involves thermally isolated solar storage and collecting from the building's interior space. A sunspace is used the most frequently in isolated gain systems. Although isolated from the occupied spaces, collection and storage are thermally connected. A sunspace is a space integrated into or attached to a building's exterior where the temperature is permitted to rise and fall outside of the thermal comfort range.

e. *Passive cooling and ventilation:* Depending on the configuration of the application, there are many types of passive solar heating.

However, passive cooling is better viewed as a collection of research areas that concentrate on the fundamental heat sinks. This arrangement is beneficial to researchers and inventors, but designers and decision-makers find it frustrating because so many practical systems require many heat sinks.

f. *Ventilative-based cooling:* substitutes warm indoor air with cooler outdoor air. flowing air across occupants' skin to chill through a convection-and-evaporation combination. In passive applications, either the wind or the stack effect supplies the necessary air movement. In a hybrid system, movement may be assisted by fans.

g. *Radiant cooling:* Everything in a structure emits and absorbs radiant radiation. If there is an outward net flow, radiation will cause building objects to cool. The long-wave infrared radiation emitted by a clear sky at night is far lower than that emitted by a building. As a result, there is a net flow upward.

h. *Evaporative cooling:* Water has been used to increase a building's thermal comfort by cascades or other means. Because energy from the air is lost as water vaporizes, the temperature drops. When water dries out, it absorbs a significant quantity of heat from the surroundings and transforms it into water vapour. As sensible heat converts to a state of latent heat, the temperature falls. There are two ways to exploit this phenomenon to cool buildings. The air will not only be humidified but also chilled if evaporation of water inside the building or at the intake of clean air. Direct evaporative cooling is the term for this technique. However, indirect evaporative cooling is the process by which the building or indoor air is cooled through evaporation without being humidified.

i. *Dehumidification:* The process of drying out water vapour from indoor air through condensation, desiccation, or dilution with drier air. Dehumidification, is therefore, the exchange of latent heat in air for the sensible heat of water droplets on surfaces during condensation and desiccation, which is the inverse of evaporative cooling and thus an adiabatic heating process.

j. *Mass*-effect cooling: the process of absorbing heat during the warm and hot phases of a seasonal temperature cycle and releasing it eventually during a cold section using thermal storage. Daily-cycle mass-effect cooling is demonstrated by night flushing, which involves drawing cold night air through a structure or building to release the heat that has been trapped within its huge floors and walls throughout the day.

II. Employing active techniques to use renewable energy resources:

i. Solar energy systems that are actively used in buildings: Buildings can use solar energy to generate electricity and heat using devices like photovoltaic panels, solar collectors, and the building integrated PV systems. Due to higher nearby buildings, which increase the probability of direct solar radiation, high-rise buildings have a greater potential for using PV panels than low-rise buildings or structures. The most significant issue is the requirements for regulating massive volumes of PV panels. Because maintaining buildings' beauty and productivity of PV panels is crucial.

ii. Active systems that utilize solar energy: The systems are made up of a collection of mechanical and/or electronic components that transform solar radiation received through collectors made for this purpose into energy in a desired form and enable this to be utilized in construction. Solar radiation can be converted into heat and electric energy using these techniques.

According to the type of energy they create, these solar energy conversion systems are split into two categories: electrical thermal PV systems that generate electricity and solar thermal systems that provide thermal energy. The following describes these systems;

a. *Thermal systems driven by solar energy: (effective solar heating systems):* are collections of mechanical and/or electronic parts that use collectors to transform solar radiation into thermal energy. This energy can then be used directly by mixing it with water, air, or another similar fluid, or it can be made usable by being evaluated in a storage unit.

   Pool water heating, climatization air preheating, and environmental heating are all accomplished using solar energy-efficient thermal systems. The fundamental tenet of thermal systems is the collection of heat through collectors, storage of thermal energy for potential future use, and distribution of that energy to pertinent domains.

b. *Solar powered water heaters:* These are systems compromised of parts that convert solar energy into heat, retain it, and disperse it across an aquatic environment. All solar water heating systems are built around heating, storing, and distributing water, as opposed to systems that vary depending on complexity and level of necessity.

   Depending on the system's characteristics, the hot water generated by the conversion of solar energy can be used directly for bathing, doing laundry, and cleaning dishes. This can also be utilized to supplement the traditional heating system.

Figure 48 Image showing installed solar panels on the rooftop of the NTU Campus Building in Singapore.
Source: OIP.WM0ji9cohdIrG6h4EdsU5QHaE8 (474×316) (bing.com)

Figure 49 Image showing vertical-axis of installed wind turbines on top of a building at the Hong Kong University campus.
Source: R.82ccaf83e4cee4cb5e950e6a7eb42500 (1600×1067) (bing.com)

c. *Photovoltaic - PV systems:* Systems called photovoltaic (PV) employ solar radiation to capture electrical energy and transform it into a form that can be used. In many diverse industries, including traffic lights, lighthouses, autos, buildings, and power plants with simple or complex structures, PV systems are utilized to generate electricity. A solar energy system generates power, stores it for future use, and then transfers it securely to the intended destinations. Building fronts and roofs have photovoltaic batteries installed to turn solar energy that strikes these reflective surfaces into energy for electricity.

d. *Wind energy systems active in buildings:* Wind energy is the world's fastest-growing renewable energy source. Wind energy, as a clean energy source, has no impact on the generation of greenhouse gases or acid rain-causing atmospheric pollutants. Wind energy is an infinite source of energy. Wind turbines can now be included in construction plans thanks to recent advances in technology. The integration of wind turbines with building architecture significantly enhances their effectiveness atop tall buildings, which is consistent with the high-performance approach to building design. Using wind turbines on towering structures with this feature allows for significant amounts of electricity to be generated.

Other renewable energy sources include geothermal energy, hydrogen, and use of biomass energy in buildings. Figure 50 shows an image of a plant diagram for biomass production.

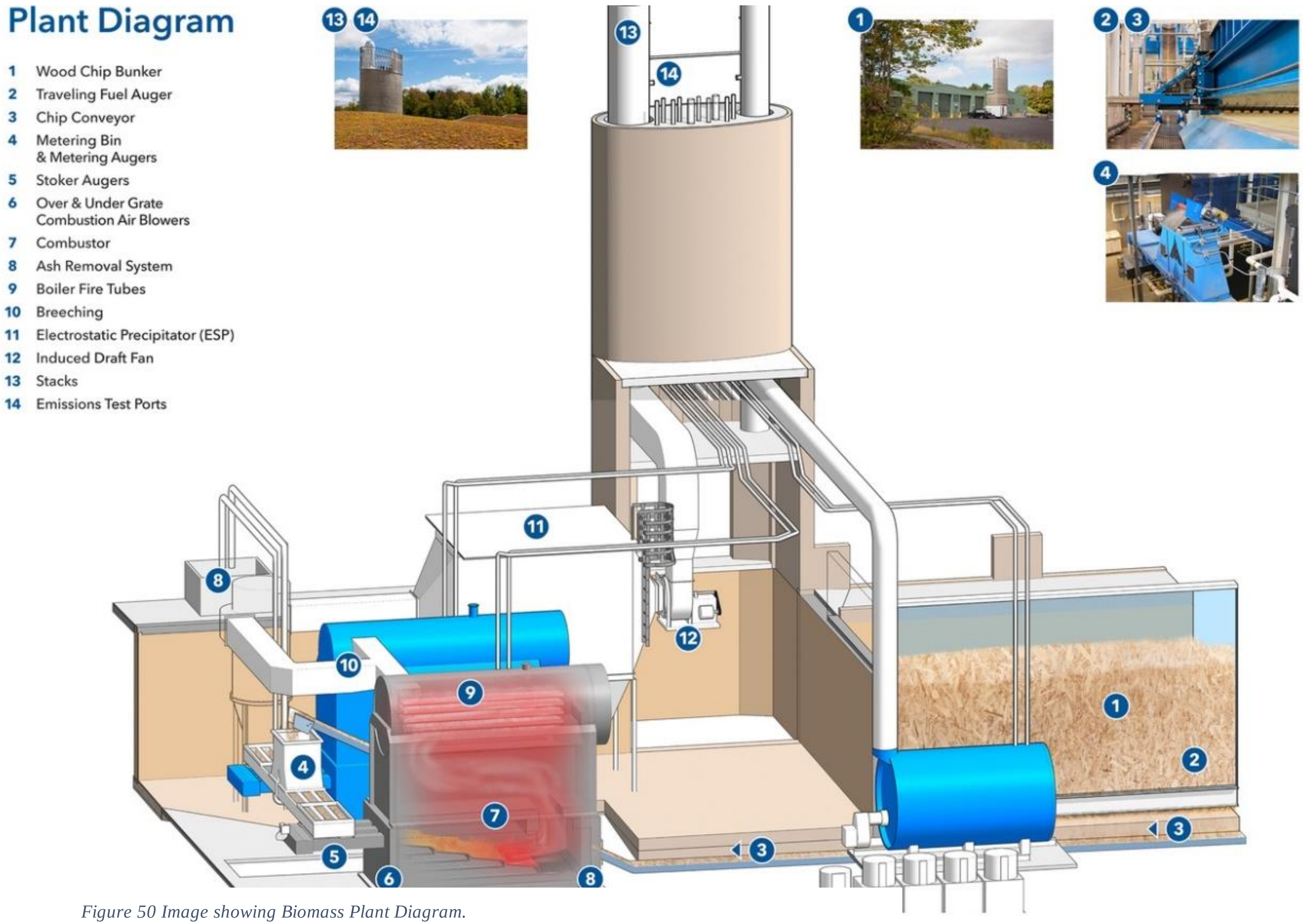


Figure 50 Image showing Biomass Plant Diagram.

Source: What is Biomass Energy? | ArchDaily

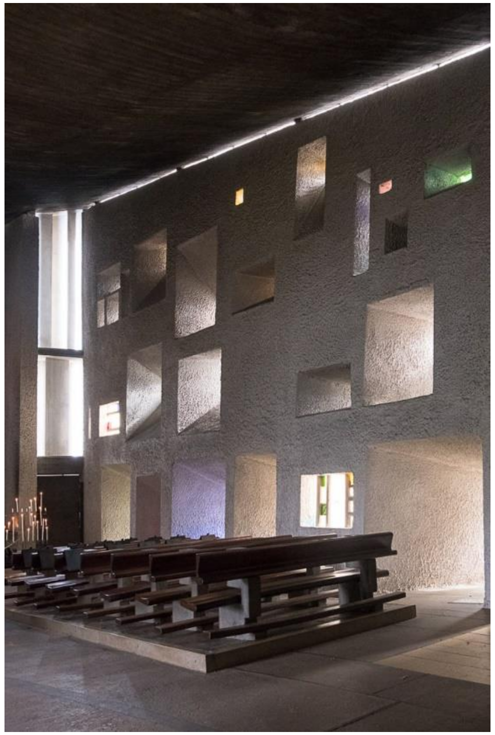


Figure 51 Image showing the interior of Notre Dame de Haut.

Source: Inside-the-chapel-of-Notre-Dame-du-Haut-Ronchamp-France-a-chapel-by-Le-Corbusier-and-a-UNESCO-World-Heritage-site-www.RoadTripsaroundtheWorld.com_.jpg (720×1080) (wp.com)

a. *Natural daylighting:* is provided by a building's most basic windows and skylights. Window and roof light orientation should be carefully considered. South and north are the best directions for natural illumination. Although the north is not exposed to radiation, it can always receive consistent, high-quality daylight. The sun radiates horizontally in the west and east directions, making it challenging to control. In contrast to the west and east directions, the sun rises at a straight angle in the south, where its influence is permanent. Consequently, it is simple to control.

Light colours should be used on window wings that direct light and light shelves to improve the amount of daylight entering the structure. Additionally, the reflectors utilized must be constructed so that they can direct light upward. For the light to diffuse, wall and ceiling surfaces must be light in colour. Recommended reflectance according to the Illuminating Engineering Society: >80% for ceilings, >50% for walls (greater if a window is present), >40% for flooring, and >25% for furnishings

The right daylighting system design and selection can contribute to increased energy efficiency and decreased environmental pollution. When properly built, windows, clerestories, and roof monitors can meet lighting requirements without unwelcome heat gain and glare

And therefore, when the desired illuminance is attained through daylighting, electric lights can be switched off or dimmed in spaces that are naturally illuminated during the day. Only by integrating light controls, sensors, and dimmers into the lighting system of those naturally lit areas would energy savings be realized. Buildings' use of daylight reduces their reliance on electric energy.

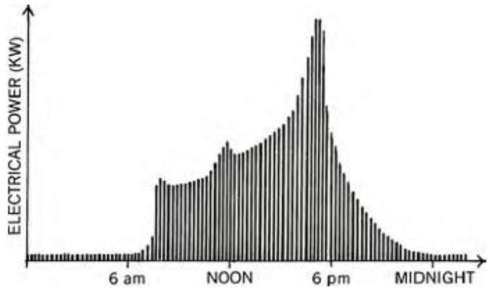


Figure 52 Image showing the graph of the maximum requirement for electricity in an office building comes on a hot season afternoon
Source: Heating, Cooling, Lighting, Norbert Lechner

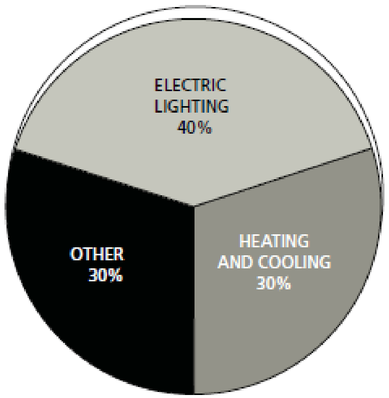


Figure 53 Image of a chart showing the typical energy consumption distribution for buildings.
Source: Heating, Cooling, Lighting, Norbert Lechner

According to a study, artificial lighting accounts for around 50% of the energy consumed in non-domestic buildings in Europe. Furthermore, it has been proved that by integrating the use of artificial and natural lighting, this consumption can be reduced by 30 to 70%. The position, size, and shape of the window, as well as the geometry and surface reflectivity of the room, all have an impact on possible savings.

Another method that natural light is employed in buildings is through daylighting systems. "Daylighting" refers to "the combination of diffused light from the sky and sunlight."

The goal of a daylighting system is to redirect a significant percentage of the incoming natural light flux to improve lighting conditions; as a result, it is often installed close to or in the building's exterior openings. Daylighting systems are divided into two categories: side lighting and top lighting. Numerous glass arrangements can let light in, whether vertical or horizontal, on the side or from the top. The most common source of side lighting is a window opening. A top lighting opening is an aperture in the ceiling or roof of a building.

2.3.2 Energy-efficient strategies in the building phase of a Project:

The construction and usage of the building are both covered under the building phase. With the incorporation of energy-saving instruments and selected low-energy construction techniques, the building stage is doable. Systems in the building have an impact on how much energy is used during construction. For instance, Hozatl and Günerhan found that frame building consumes less power overall than the use of reinforced concrete frame structures in their research. Buildings constructed of the same resources experience variations in energy consumption at the same pace as those made with distinct materials. The energy usage of the popular reinforced concrete frame construction system was investigated using the following three construction methods:

1. Conventional frame building system: The conventional building system's most notable feature is that the entirety of production is carried out on the construction site with the help of a lot of labour-intensive labour. When compared to other systems, the traditional method uses less energy because of the characteristics of the machinery (concrete mixer, roof crane) used in the stages to create and cast concrete.
2. Concrete masonry tunnel system: A specific upfront investment is needed for the tunnel form masonry system. The technology is appropriate for extensive and ongoing projects. Energy utilization is high because big, massive forms are carried using lifting cranes that take a lot of energy. The task of curing with a concrete plant and intra-tunnel heater raises the energy consumption of the system
3. Precast construction system: Energy consumption is particularly high since many systems that are realized in the building area are created in the manufacturing facility. In these systems, lifting cranes are used to move components from cars to the workplace, store them, and mount them. For this reason, a significant amount of energy is used throughout these periods as well. While heavy-load vehicles that deliver ready-made building components from a production facility to a construction site cause traffic congestion, they also use more energy. It can be concluded that manufacturing processes for tunnel form, precast framework, and precast panel building systems have a significant negative impact on

consumption of energy and emissions.

On the other hand, traditional systems' energy consumption has a greater negative impact on the creation of solid waste. There are various ways to create buildings using the same material, as shown by the reinforced concrete building system. Lifting cranes, concrete pumps, and transport mixers are examples of large machinery that use a lot of energy. Because of this, it is preferable to use less energy-intensive building techniques as long as the structure's quality is not compromised.

The process uses the bulk of the energy in buildings when in use. Almost 90% of the energy used in buildings is used for usage and maintenance, according to a report from the World Business Council for Sustainable Development (WBCSD). Applications that are highlighted during the design phase improve a building's operational energy efficiency. Additionally, when used, the applications listed below can save a significant amount of energy.

Supporting improvement for multiuse: It is encouraged by sustainable development to combine residential, commercial, office, and retail locations. People might so choose to live close to their places of employment and commerce. Due to this, the development of a community differs from conventional suburbs. The possibility of operating 24 hours a day also makes the environment safer.

Integrating design and public transit: On an urban scale, sustainable architecture should be planned to assist public transportation. Numerous parking spaces are required due to the large number of vehicles that enter and exit the area regularly, which contributes to traffic congestion and air pollution. Using energy-efficient lights and appliances, such as the light-emitting diode (LED), is one of the most energy-efficient and quickly evolving lighting technologies available today. Control of the lighting needs is determined by a building's architecture. The size, placement, and orientation of the windows and the position of the buildings will all affect the requirement for illumination during the day.

The use of automated controls, which depend on the direction in which the building's windows face, the amount of daylight present, and how the space is being utilized, lessens the need for lighting. High-efficiency ventilation, heating, and cooling equipment the amount of energy used by the HVAC (air conditioning, ventilation, and heating) systems in buildings is a major factor. The following is the relationship between air conditioning systems and building requirements: High-performance building envelopes reduce the need for HVAC systems. In buildings that have been carefully and thoughtfully constructed, HVAC systems might be used less. Increases in HVAC system efficiency might save you a lot of money.

The overall reduction will depend on how much heating or cooling is needed throughout the facility, for instance, if a heating boiler's or air conditioner's energy efficiency is increased. In an adequately insulated building envelope, the HVAC system's energy requirements are reduced. The need for cooling, heating, and ventilation can be reduced by carefully arranging the building's division into thermal zones of the right size.

2.3.3 Energy-efficient strategies in the post-construction stage of a Project:

When the usage phase is finished, the post-construction phase begins. The building will be demolished, recycled, and destroyed during this phase. Recycling the building components and resources that were utilized to construct the buildings is crucial at this phase. Repurposing buildings rather than dismantling them once their intended purposes have been fulfilled conserve resources like raw materials, water, and energy. Reusing building components from structures whose demolition has been decided upon, such as roof trusses and woodwork, should be possible. Recycling construction materials must be separated after the saving of suitable building compositions. By protecting the raw materials in this way, the building material that will be produced is spared from having to use energy to process the raw materials. When demolishing structures, it's important to utilize as few machines and pieces of equipment as possible and to choose pieces of equipment that are energy-efficient.

2.4 Tropical Climate

These are the climates where heat-related issues predominate. Where the average annual temperature is at least 20°C, buildings function to keep the inhabitants cold rather than warm for most of the year. (Koenigsberger, 1973). The Tropics of Cancer (23.50 N of the Equator) and Capricorn (23.50 S of the Equator) contain these climatic zones.

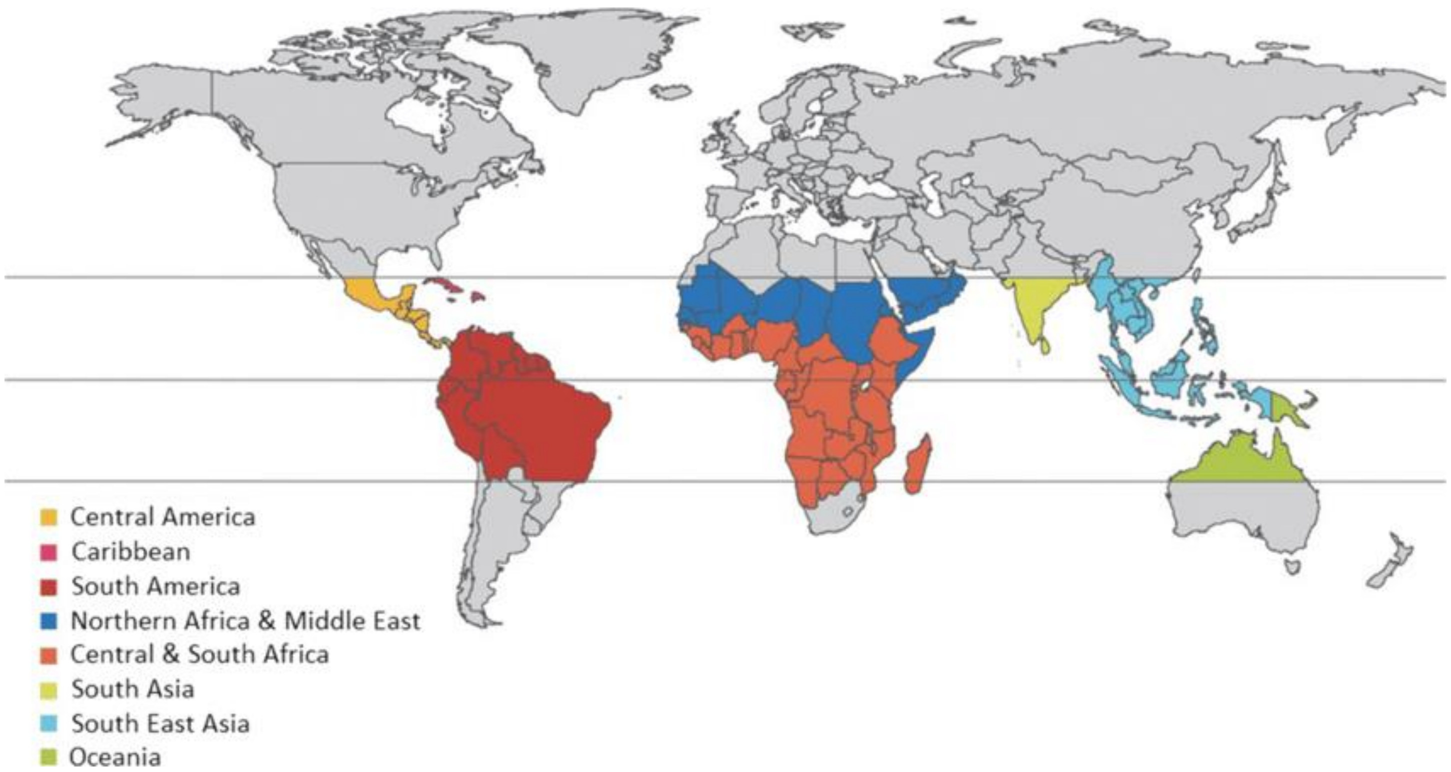


Figure 54 Image showing map of regions with Tropical climates.
Source: https://www.researchgate.net/publication/337292842/figure/fig1/AS:825729344348160@1573880625009/Tropical-regions-Edelman-et-al-2014.png

According to Koenigsberger, 1973, there are six types of climates found in the tropics: these climates are:

Warm Humid Climate, Warm Humid Island Climate, Hot Dry Desert Climate, Hot Dry Maritime Climate, Composite or Monsoon Climate, and Tropical Upland Climate.

For thesis, we shall study the characteristics of tropical Upland climate

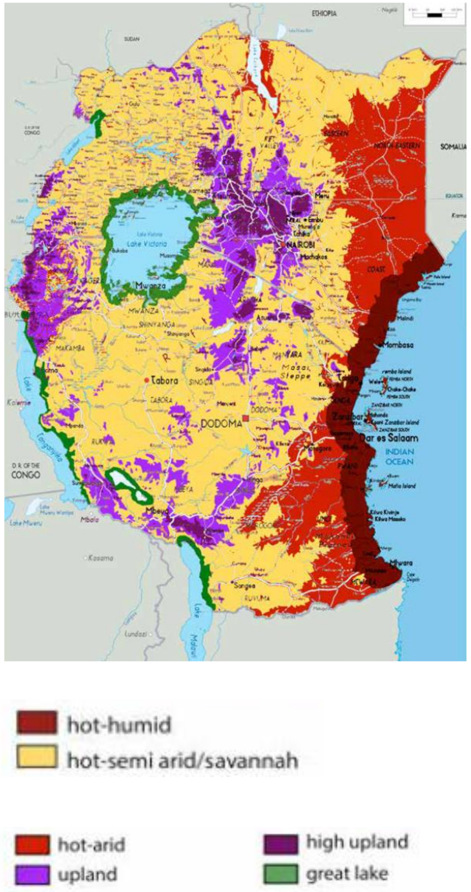


Figure 55 Image showing the Tropical Climates in East Africa.
Source: Sustainable Building Design for Tropical Climates Principles and Applications for Eastern Africa

Tropical Upland Climate

i. Such climates exist between the two 20°C isotherms in mountainous regions and plateaus higher than 900 to 1200 m above sea level. Cities with similar regions include Addis Ababa, Bogota, Mexico City, and Nairobi.

ii. Seasonal differences are modest in highland regions near the Equator, but seasons follow those of the neighbouring lowlands as one moves away from the Equator.

iii. The air temperature in the shade falls with altitude. At an elevation of 1,800 m, daytime mean maxima can range from 24 to 30°C, while nighttime mean minimum can range from 10 to 13°C. It may go below 4°C in certain areas, and ground frost is not unusual. The annual range varies with latitude: in the Equator, it is little, but at the Cancer and Capricorn tropics, it can range from 11 to 20°C. The humidity ranges from 45 to 99%, while the vapour pressure ranges from 800 to 1600 N/m2.

iv. Precipitation varies, but it is rarely less than 1000 mm. Rain frequently falls in heavy concentrated showers with an intensity of up to 80 mm per hour. The sky is usually clear or partially cloudy to a degree of about 40%. The sky is cloudy during the monsoon rains, and the clouds are heavy and low.

v. During clear periods, solar radiation is intense and direct, stronger than at the same latitude but at sea level. Ultraviolet radiation is especially powerful at higher elevations. As the cloud cover rises, it gets more dispersed.

vi. Winds are variable, primarily from the northeast and southeast, but can be significantly diverted by local topography. Wind speeds rarely surpass 15 m/s.

vii. During the wet season, the vegetation is green but not extremely lush, but it may wither during the dry season, when the ground might turn brown or red. When it rains, the soil becomes wet but rapidly dries. At night, there is a lot of dew. During the dry season there is a significant loss of radiation at night, which may result in the production of radiation fog. Thunderstorms with a high percentage of electric discharges - air to ground. Hail may also fall.

Figure 56 Image showing aerial view of Nairobi City.

Source: 18301ac413480f70c50a20858740d460.jpg (1200×800) (pinimg.com)

2.5 Bioclimatic architecture

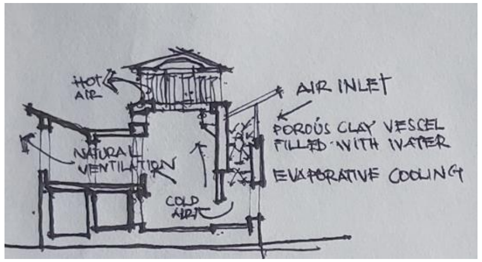


Figure 57 Image showing Evaporative Air Cooling in Egypt by Hassan Fathy. Source; Author modified.

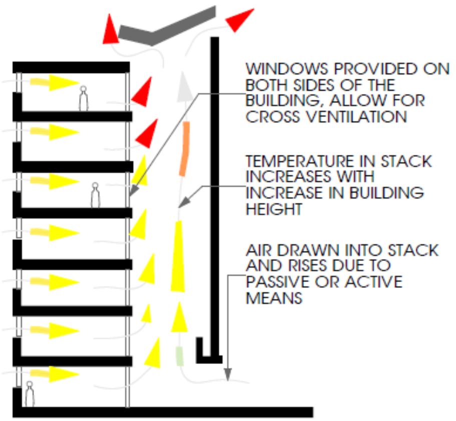


Figure 58 Image showing Stack pressure driven by natural ventilation. Source Author, 2023

Bioclimatic architecture is a strategy that makes use of the climate by applying the ideal design components and construction technologies to manage the heat transfer process. As a result, this regulation encourages energy conservation and ensures that buildings are comfortable (GOULART and PITTA, 1994; ERG, 1999). This usually employs passive strategies related to this understanding and the knowledge of local climatic.

The primary rule of bioclimatic design is to make use of localized bioclimatic factors for the advantage of both the architectural and natural surroundings. This strategy must always be founded on a comprehensive multidisciplinary investigation of each case, starting with ecosystem-specific details and extending through cultural considerations and economic analyses. In the end, the safe and comfortable buildings that are constructed do not hurt the environment; rather, they improve its health and enrich biodiversity.

To match current expectations, the constructed environment must guarantee a wide enough temperature range, appropriate moisture, and air exchange, excellent acoustic characteristics, and well-planned lighting. Additionally, common expectations for aesthetics should be met. These specifications for lighting and the interior environment are typically what cause some significant issues. While plant systems are far less typically utilized in bioclimatic settings in favour of the approaches covered later in the chapter, the utilization of sources of renewable energy is advocated. Figures 57 and 58 show images of principles used in bio-climatically designed buildings.

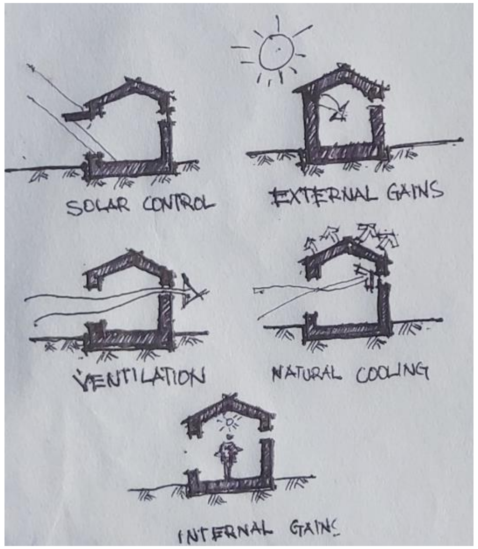


Figure 59 Image showing some design strategies for Bioclimatic Buildings.
Source: Bioclimatic (Natural Cooling) - Tropical Architecture (tropical-architecture.blogspot.com)

The most obvious component of a building's response to specific conditions in hot climes is its effectiveness in cooling, which is often based on air circulation and the usage of water. The thermal load of the façade is lessened by overhanging roofs, louvers, trees, and other shading components. In warmer climates, thermal massing, and other insulation systems are also utilized to prevent daytime overheating and release the heat slowly at night.

Three main types of passive cooling systems that rely on natural ventilation and are widely used around the globe:

i. Based on the air pressure differential throughout the building, cross ventilation
ii. Stack effect-based chimney ventilation
iii. based on the overpressure and under pressure, wind catchers and towers

The unpleasant truth is that plant air conditioning devices are now widely used in public as well as private settings, notably in offices, stores, governmental buildings, and transportation hubs, among other locations, despite numerous natural cooling measures developed in the past. These methods are not only expensive and energy-intensive, but they also harm the environment and people's health. As a result, the walls, roofs, and floors are massively thick. These substances retain heat throughout the day and let it out at night.

Figure 60 Image showing Ken Yeang's Bioclimatic building; Menara Mesiniaga.

Source: The Bioclimatic Skyscraper: Kenneth Yeang's Eco-Design Strategies | ArchDaily

The idea of bioclimatic architecture allows the fusion of cutting-edge technologies and conventional approaches to a home's climatic adaption. One of the most important characteristics of this phenomenon is how the bioclimatic approach aids in the most effective application of both passive and active techniques.

Ken Yeang contends that the integration of so-called eco infrastructures, which respect the ecology on all attainable levels and go beyond straightforward technological infrastructures, should serve as the foundation for the entire built environment. There are four distinct groups in Eco Infrastructures. The first, "Green," refers to the diversity of the environment, wildlife, animal and plant migrations, ecosystem complexity, and other topics.

The second category consists of "Gray" engineering systems, which are focused on renewable energy, low-impact technology, and zero 0% emissions of CO2. The third category, referred to as "Blue," is connected to water management. The need to preserve clean water resources in the world is critical, hence gray water recycling and rainwater collection are given major consideration. Figure 60 shows the image of Ken Yeang's Menara Mesiniaga.

The last "Red" group addresses all of human culture's influence. This includes societal and cultural norms, legal requirements, as well as current user expectations for indoor microclimate, acoustic comfort, and visual comfort, among other things. An important issue that must be considered in that area is the human impact on the surroundings, including suitable choice of materials that rely on life cycle analysis studies. By analysing all steps required to manufacture, use, and dispose of a structure, this method enables the assessment of potential consequences connected with products and activities.

Eco Infrastructures' core concept is a method focused on ongoing ecosystem preservation, restoration, and healing, particularly concerning biodiversity and equilibrium. This comprehensive strategy, which highlights the value of in-depth analyses of biological processes and climatic conditions, is not only important for achieving energy certification but also a unique feature of bioclimatic design. The concept of bioclimatic building could seem a little utopian because of its complexity. Nevertheless, can apply this concept to actual buildings thanks to modern understanding and technology: Engineering systems classified as "Gray" in the second category are those that emphasize renewable energy, low-impact technologies, and zero CO2 emissions. The third category, referred to as "Blue," is connected to water management. Gray water reuse and rainfall collecting are given significant consideration since it is imperative to protect clean water supplies worldwide. Below is a discussion of the next three cases of highly developed, completed bioclimatic buildings.

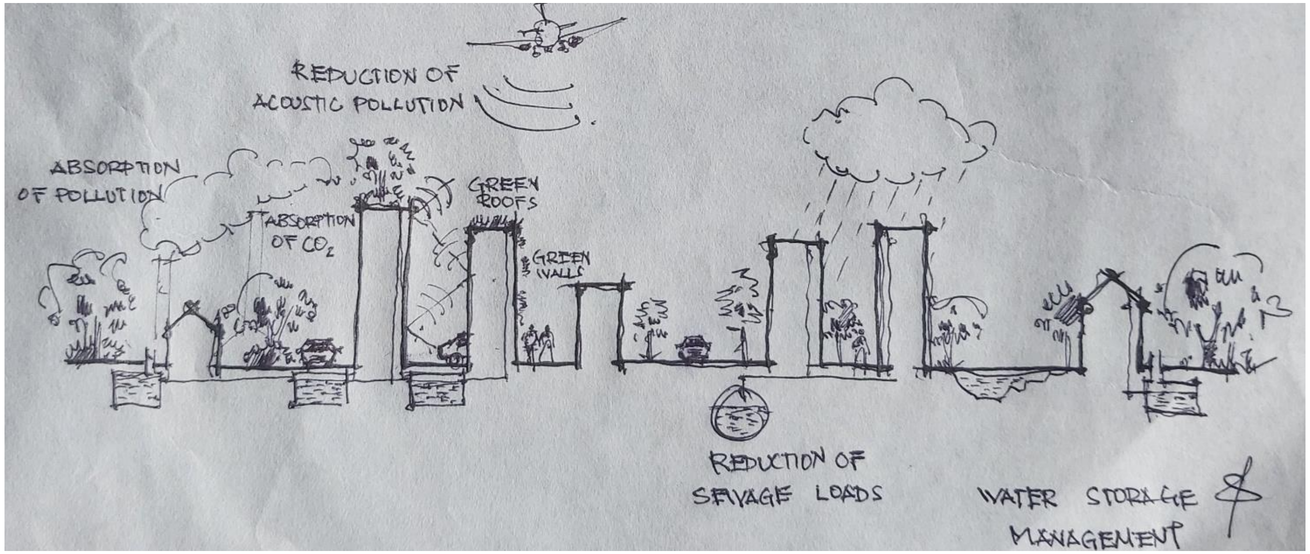


Figure 61 Image showing an Eco-infrastructure core concept.

Source: Author modified, 2023

Figure 62 Image showing Solaris 2011. Singapore, by TR Hamzah and Yeang bioclimatic image. C TR Hamzah and Yeang.

Source: Solaris building in Singapore | Skyscraper architecture, Architecture, Futuristic architecture (pinterest.co.uk)

Case Study 01: Solaris, 2008-2010, Fusionopilis Singapore, TR Hamzah, and Yeang

The Solaris Complex in the city of Singapore, which was finished in December 2010, was created by TR Hamzah & Yeang. Two towers that house office space and research facilities make up the structure. The most significant project factors were the local environment and climate. Preliminary investigations included an in-depth, multilayer study on environmental factors such as wind direction, temperature, humidity, and solar route. The designers concentrated on the repair and richness of the ecosystem, which had been seriously injured because the building was situated in Fusionopolis, an older army base.

Solaris' position required the usage of a bioclimatic system with a climate-responsive exterior and roof due to how near it was to the equator. The sun-path analysis led to the conception of extended shading elements, such as white shading louvers, roofs, and overhangs. They considerably minimize solar gains and glares, and their shape is directly impacted by the east-to-west sun path. The green spiral ramp around the building's perimeter, however, is the most stunning element in the entire architectural design. The 1500-meter-long landscaped ramp was created to provide continuity between the natural environment and the best possible relationship to the built world. It is three meters deep at its narrowest point and has been finished with the service path needed for plant maintenance. As a result, TR Hamzah & Yeang constructed a walkway park linking One-north Plaza at the bottom of the Solaris complex with the two towers' roof gardens, each of which has nine and fifteen stories. The building's tallest point is 79 meters, and a sizable atrium in the centre unites the two parts.

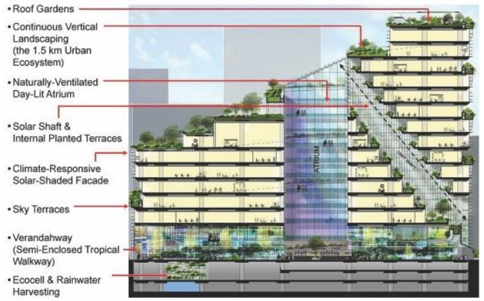


Figure 63 Image showing Solaris 2011, Singapore, by TR Hamzah and Yeang section
Source: SOLARIS, Fusionopolis (Phase 2B), One North Singapore - Greenroofs.com)

Figure 64 Image of Solaris,
Source:
singapore_science_center_ing020608_1.jpg (596×800) (e-architect.com)

The ramp enables all of the building's green zones to be readily accessed by the tiny living things.

In this sense, architecture does not act as a barrier within the ecosystem, but rather aids in its integration, promoting health and increased biodiversity.

To fill as much area with flora and provide a wide variety of vegetation, the building corner was turned into wider terraces that are also used for entertainment. This concept (7,734 m2) allowed for an exceptional percentage of 108% of the whole planted area to the site area. With this much greenery, irrigation requires a lot of water. A sizable rainwater treatment system was implemented due to Singapore's high average annual precipitation and as a logical result of the bioclimatic approach. It comprises of a symphonic drain on the roof and drainage downpipes around the surrounding ramp. On top of the taller tower is a rainwater harvest rooftop transfer tank, and a second rainwater harvest rooftop transfer tank is utilized to store gathered water in the basement.

The majority of Solaris' irrigation needs may be met by rainwater tanks, which have a total storage capacity of 700 m3. An integrated fertigation system delivers essential organic nutrients. Every type of plant fertilizer is safe for the environment and is applied in a way that doesn't interfere with building occupants.

The atrium in the middle of the two towers helps to evenly distribute air and light throughout the structure. The concept of bioclimatic architecture is used in Solaris to connect traditional cooling techniques found in hot, humid climate zones with cutting-edge technology.

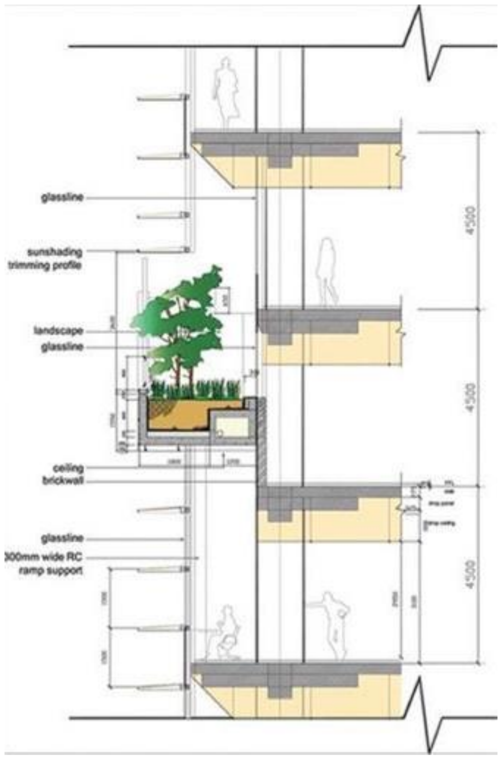


Figure 65 Image showing a construction detail of Solaris.

Source: Solaris, 2008-2010, Fusionopilis Singapore - Bing images

Cross ventilation and convection are used to completely passively chill the atrium. However, to ensure that the system is adequate and will give good thermal comfort without too rapid air movement, the airflow in the atrium was examined using Computational Fluid Dynamics (CFD) models. The roof has an adjustable glass-louvered skylight that is regulated by weather-responsive sensors to allow stack cooling while also shielding the interior space from the elements.

Solaris' public spaces can receive the most sunshine because of the atrium's transparent walls and ceiling. The so-called solar shaft is another visually appealing component that helps workplaces receive the best possible daylighting. It crosses the building diagonally and provides natural light to the rooms that are placed in the deeper sections of the construction. The exterior shading louvers are also designed to guide light into the building by producing two light shelves. The eco-cell, which is located in the northeastern corner of the building, finished the light distribution. The eco-cell's function is to provide ventilation air and to let sunlight into the parking area. The extension of the plants below the ground surface became feasible with the formation of the link connecting the ramp's upper and lower parts.

The adoption of environmental principles in Solaris produced a stunning structure with a high level of user comfort as well as notable energy consumption reductions. The building's systems are optimized in a variety of ways. For instance, when enough sunshine is detected, light sensors that measure the illumination level immediately turn off artificial lights.

Figure 66 Image of Solaris,

Source: SOLARIS, Fusionopolis (Phase 2B), One North Singapore - Greenroofs.com

Figure 67 Image of Solaris,

Source: SOLARIS, Fusionopolis (Phase 2B), One North Singapore - Greenroofs.com

Thanks to thoughtful façade shading and Low-E double glass, the complete system has an external thermal transfer value (ETTV) of 39 W/m2. Solaris consumed 36% less energy overall than comparable buildings.

The Solaris indicates new avenues for modern architecture development, and its budget made it possible for some excellent technology solutions. This example makes it possible to put new ideas and technology into practice, which should result in the highest levels of energy efficiency and harmonious relationships between human civilization and the environment. To learn from and draw conclusions about how to use modern knowledge to produce architecture that is precisely inscribed into local biological and climatic variables, it is crucial to evaluate these buildings.

In summary, the Solaris building has employed the following environmental parameters: sun path, humidity, temperature, wind direction, and biodiversity. Bioclimatic strategies employed are

1. Climate responsive façade
2. Roof construction – rainwater harvesting, landscaping,
3. Use of atrium for ventilation and light
4. Use of light shelves
5. Eco cells allow sunshine to enter the parking and allow for ventilation

Case Study 02: Developed in Partnership with the City of Melbourne, Council House 2 CH2) Office

In collaboration with the City of Melbourne, the Council House 2 (CH2) office building's inhabitants were included in the design of the holistic system. The design adheres to a paradigm that promotes a more symbiotic interaction between urban areas and their surroundings.

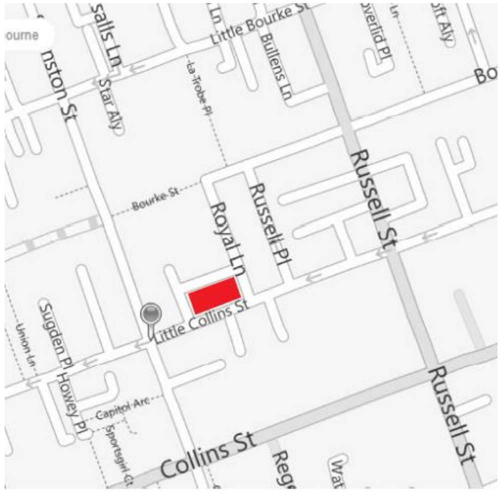


Fig. 68 Image showing the location map of the CH2 building.

Source; CH2 Melbourne City Council House 2 / DesignInc | ArchDaily, 2023

The location is situated on Little Collins Street in the heart of Melbourne. Its extended northern and southern boundaries are shaded to some extent on the east and north by nearby structures. A current retail Café is visible from the open West façade.

The subtropical oceanic climate of Melbourne features moderate winters and agreeably warm summers.

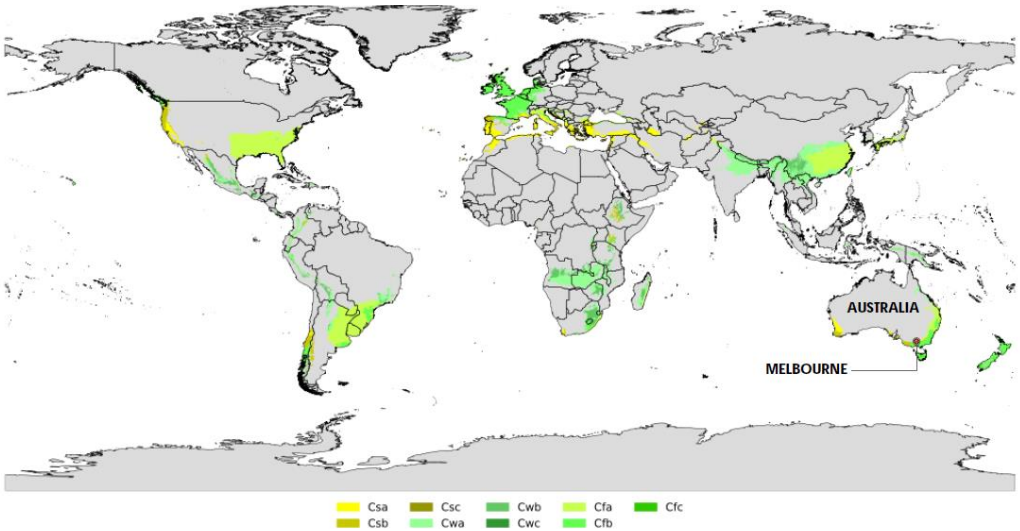


Fig. 69 Image showing CH2 in the context of the climate.

Source:

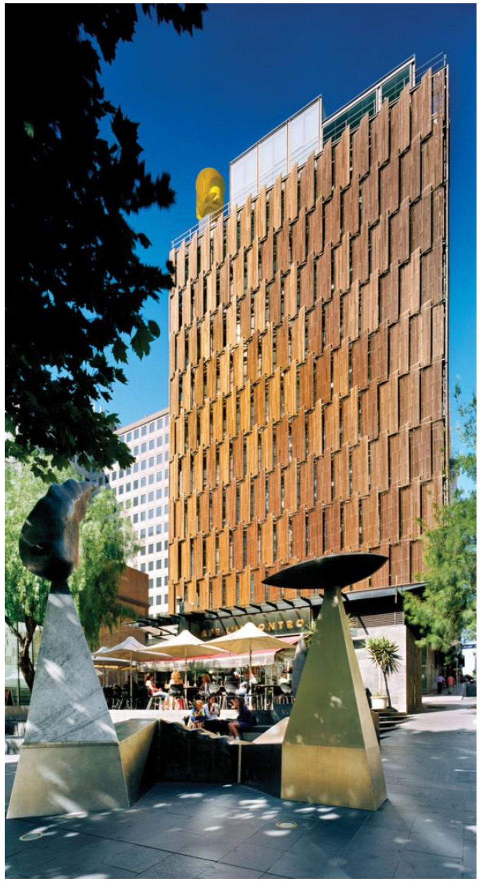


Figure 70 Image showing the CH2 building.

Source: CH2 Melbourne City Council House 2 ArchDaily

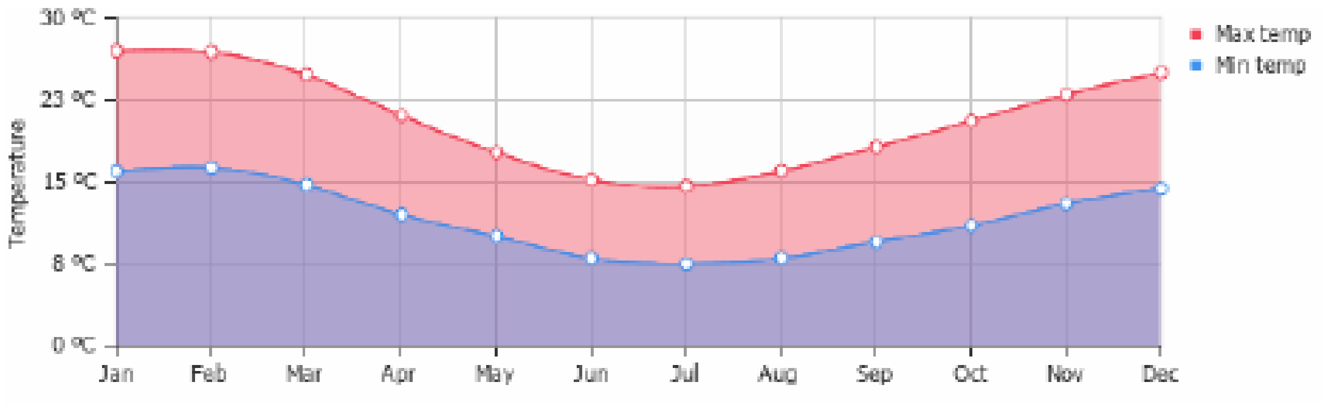


Fig. 71 Image showing the graph of temperature in Melbourne Australia.
Source: ArchDaily

Fig. 72 Image showing the graph of sunshine in Melbourne Australia.

Source: ArchDaily

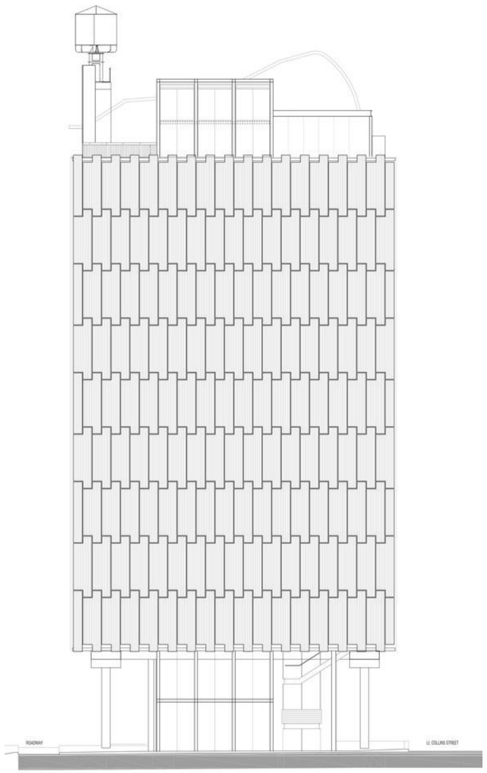


Fig. 73 Image showing West Elevation of the Council House Building.
Source: Gallery of CH2 Melbourne City Council House 2 / DesignInc - 16 (archdaily.com)

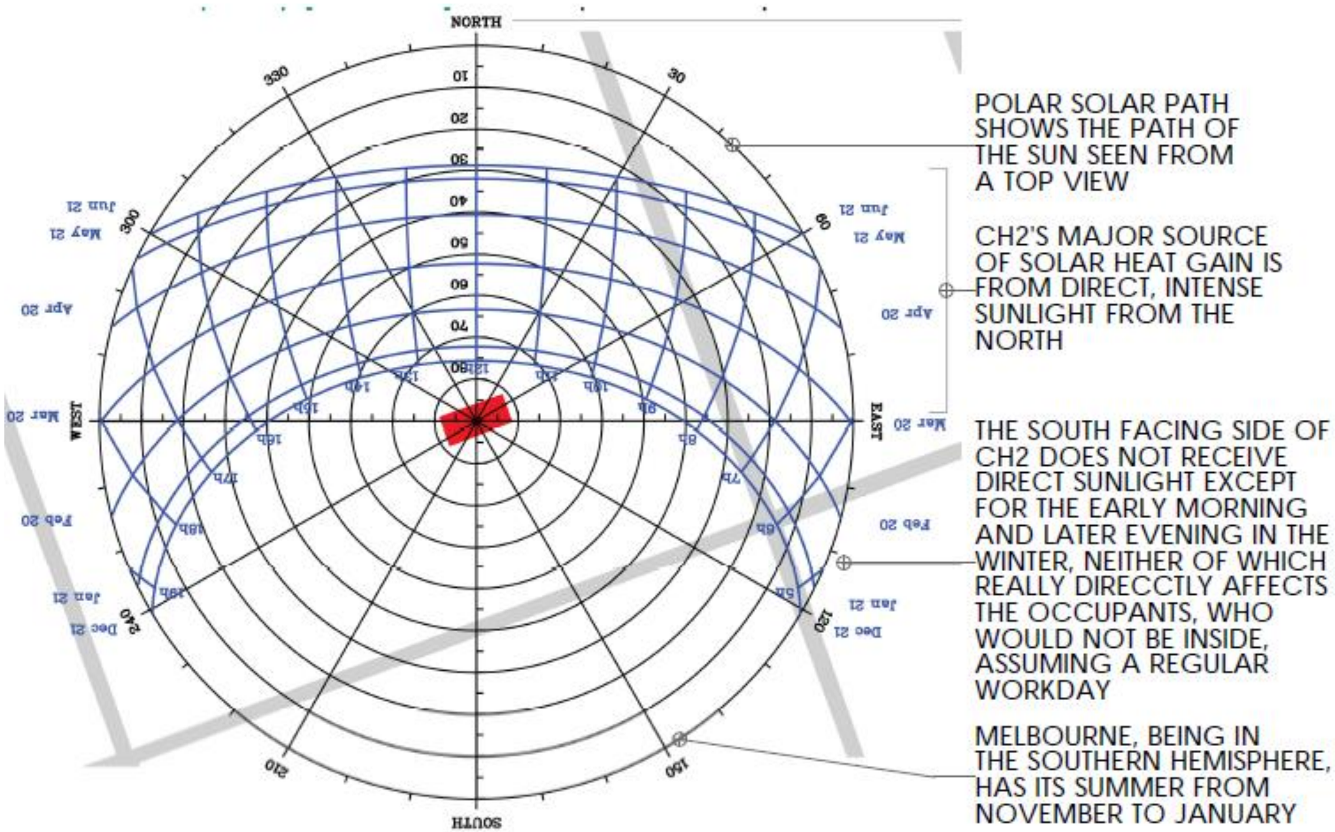


Fig. 74 Image showing solar heat gains on the building.

Source: Author, Modified 2023

Fig. 75 Image showing the CH2 shower towers.

Source: CH2 Melbourne City Council House 2 / DesignInc | ArchDaily, 2023

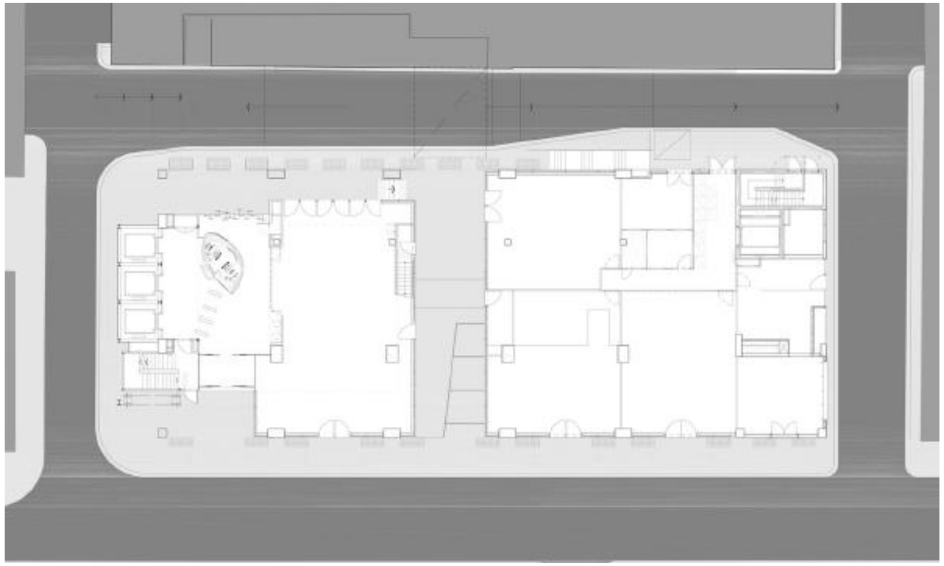


Figure 76 image showing the plan of CH2 building.

Source: CH2 Melbourne City Council House 2 / DesignInc | ArchDaily, 2023

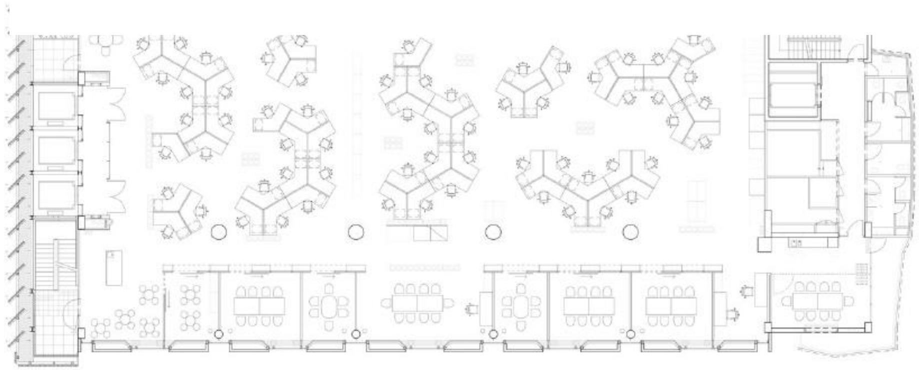


Fig. 77 Image showing the office plan of CH2 building.

Source: CH2 Melbourne City Council House 2 / DesignInc | ArchDaily, 2023

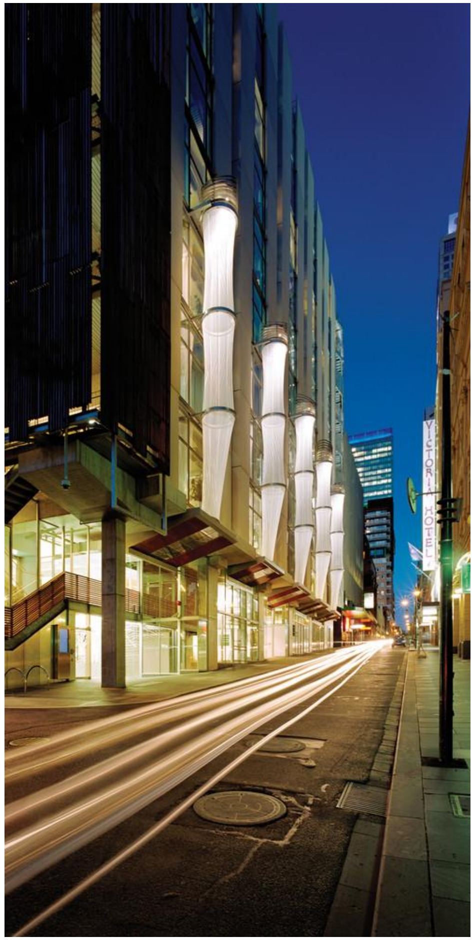


Fig. 78 Image showing the shower towers on the Council House building. Source: Fig. 5 image showing CH2 office interior.

Source: CH2 Melbourne City Council House 2ArchDaily, 2023

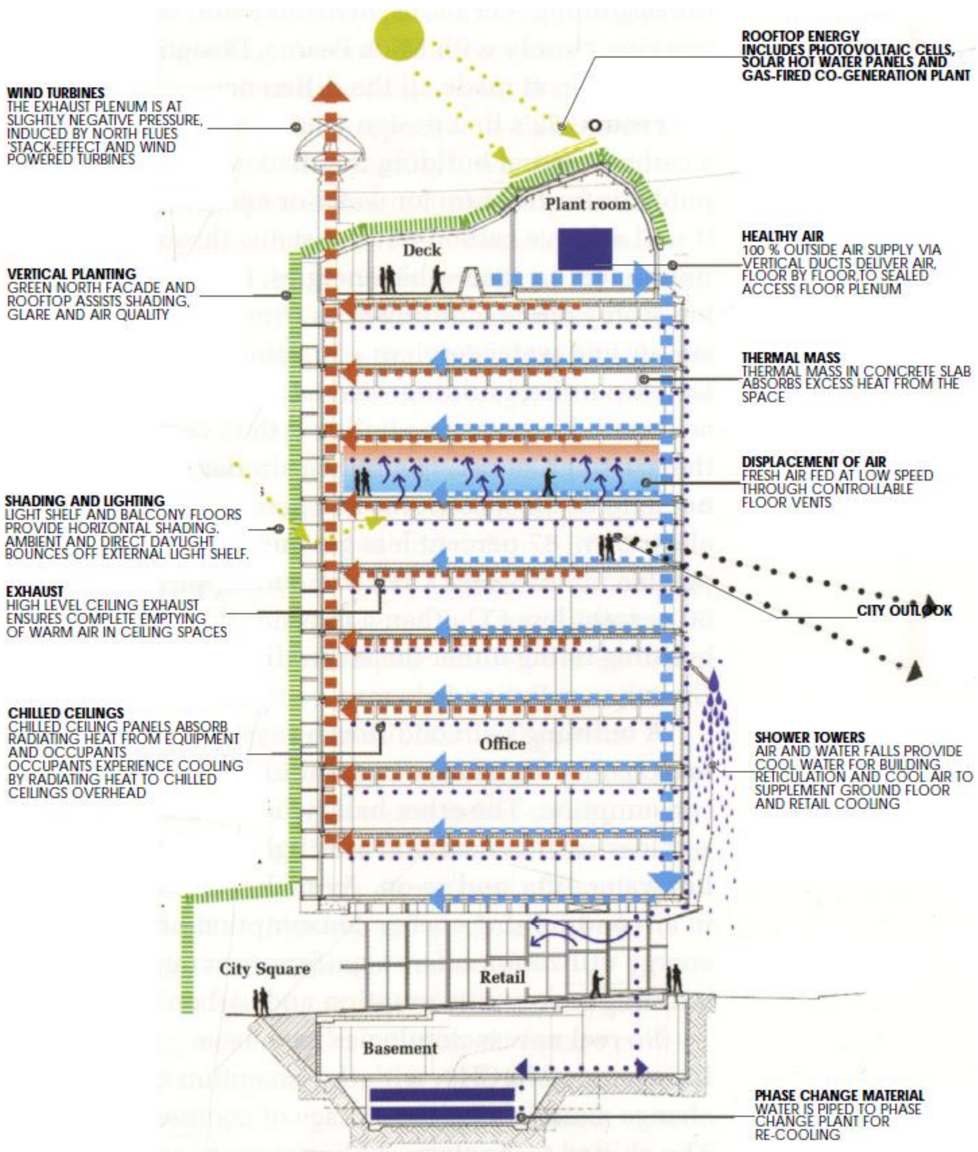


Fig. 79 Image showing Section through the CH2 Building.
Source: Gallery of CH2 Melbourne City Council House archdaily.com), 2023

Fig. 80 Image showing the Council House office interior.

Source: CH2 Melbourne City Council House 2, 2023

Fig 81 Image showing the wind turbines on the Council House Building 2

Source: CH2 Melbourne City Council House 2 / DesignInc | ArchDaily, 2023

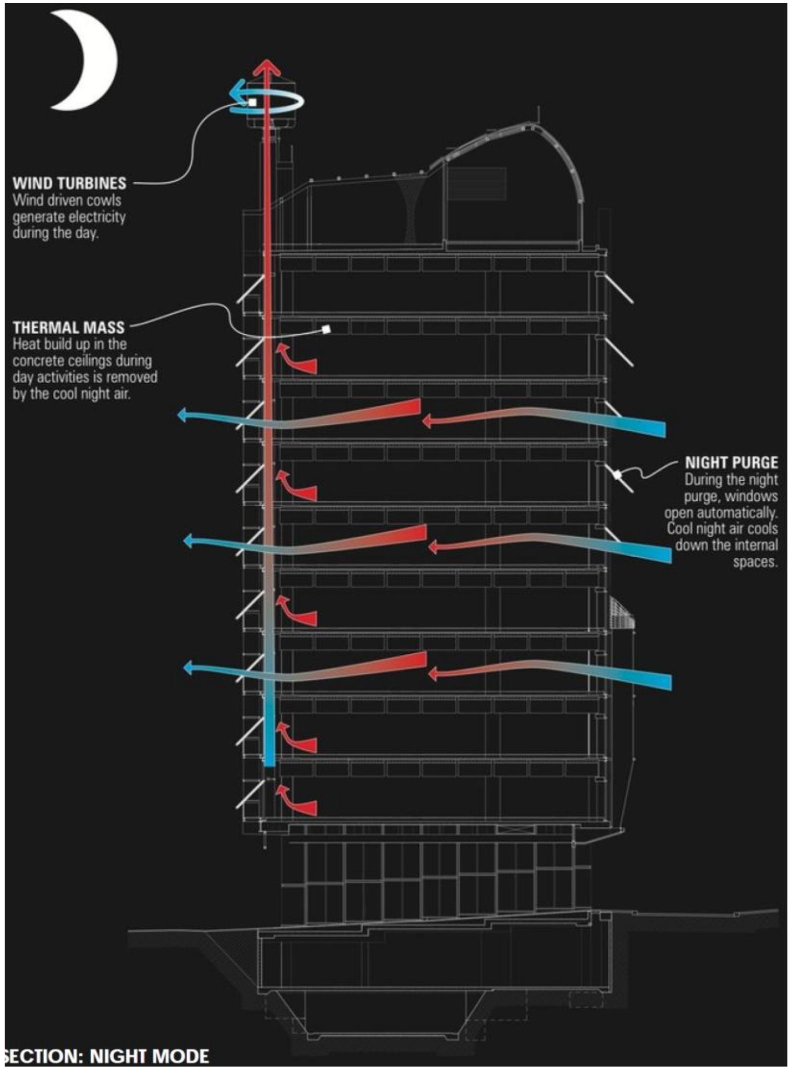


Fig. 82 Image showing Section through the CH2 Building.

Source: Gallery of CH2 Melbourne City Council House 2 / DesignInc - 16 (archdaily.com), 2023

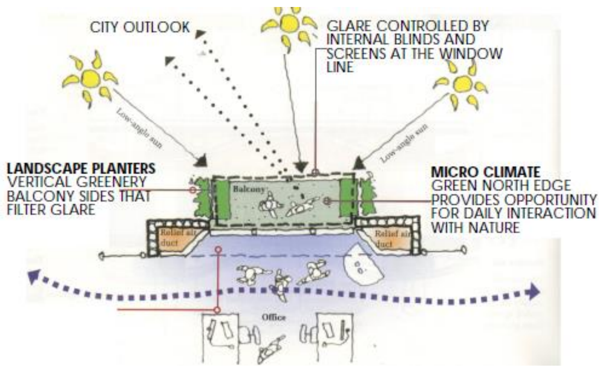


Fig.83 Image illustrating Window shelf detail.

Source: Author modified

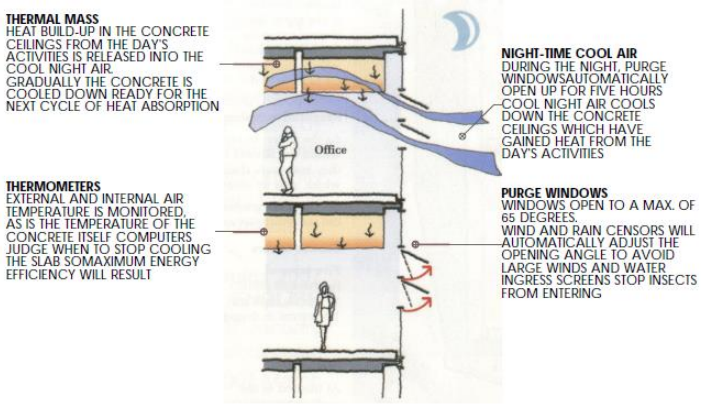


Fig. 84 Image illustrating part detail on the façade.

Source: Author Modified

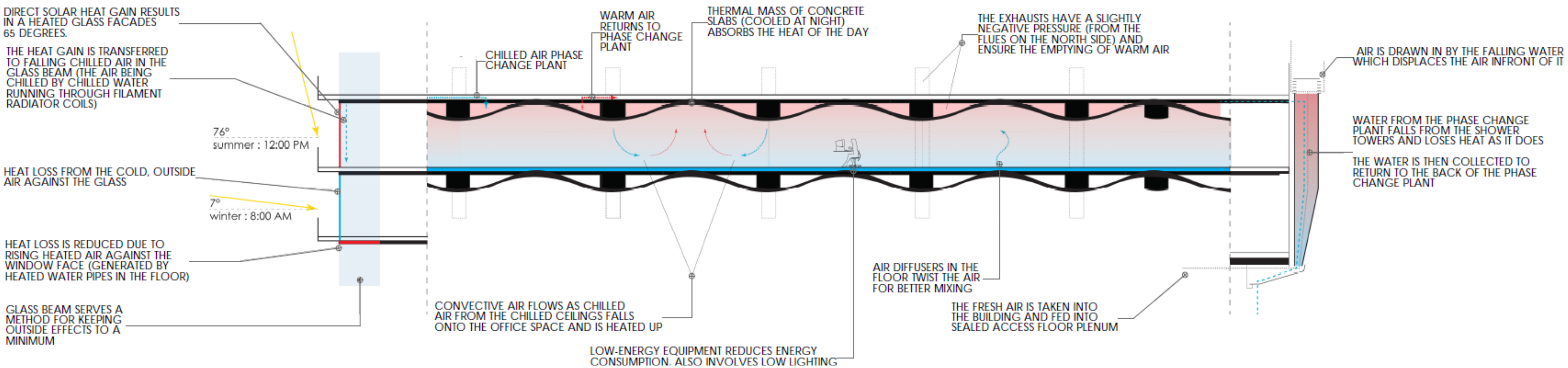


Fig. 85 Image illustrating a sectional detail of CH2 building.

Source: Author modified, 2023

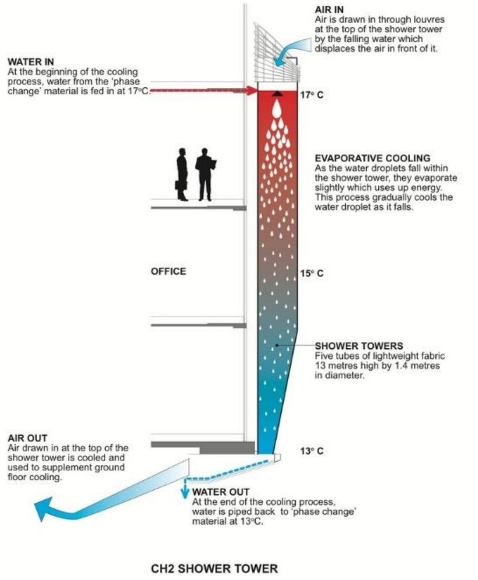


Fig. 86 Image illustrating shower tower.

Source: CH2 Melbourne City Council House 2 / DesignInc | ArchDaily, 2023

The City of Melbourne seeks to achieve zero emissions for the city by the year 2020. This strategy will be significantly impacted by the commercial buildings' 50% decrease in energy usage. CH2 was piloted to provide a real-world example of the growth of the local market. The brief requested a building that generated a premium-grade construction while utilizing passive energy technologies to the greatest extent possible.

CH2 incorporates both literal and metaphorical representations of environmental goals into its architectural design. The dynamic wavy concrete flooring structure that is crucial to the building's cooling and heating systems is inspired by nature, as are the façades that control the temperature, the daylighting techniques, the tapering ducts for ventilation, and the façades themselves.

As important as the building's environmental benefits are the capacity to provide fully fresh air to all residents with a complete air exchange every half hour. Within five to ten years, the building will recover the cost of all its innovations due to the advantages of higher indoor air quality and conservative energy cost predictions.

In summary, CH2 building has employed the following environmental parameters: sun path, humidity, temperature, wind direction, and biodiversity. Bioclimatic strategies employed are

1. The architecture depends on air and water to regulate the environmental conditions of the wide-open areas.
2. Use of sun shading devices. These louvers are made of recycled timber, automatically pivoted according to the position of the sun.
3. Balconies with gardens. These offer a microclimate thus cooling the inside of the building.
4. Use of task lighting in office spaces. This reduces the amount of energy consumed in the building.

5. Employ high thermal mass. The building opens up at night for 5 hours cooling the inside. This helps to reduce the cooling of the building by 20%.
6. The hanging gardens that span the whole length of the northern wall are watered with recycled water from the sewage mining facility.
7. Use of evaporative cooling using tower showers.
8. Use of wind chimneys to cool the building.

Figure 87 Image showing CH2 Building.

Source: OIP.4MoVmuiYVTNHFCcM9l_zcwHaLJ (474×713) (bing.com)

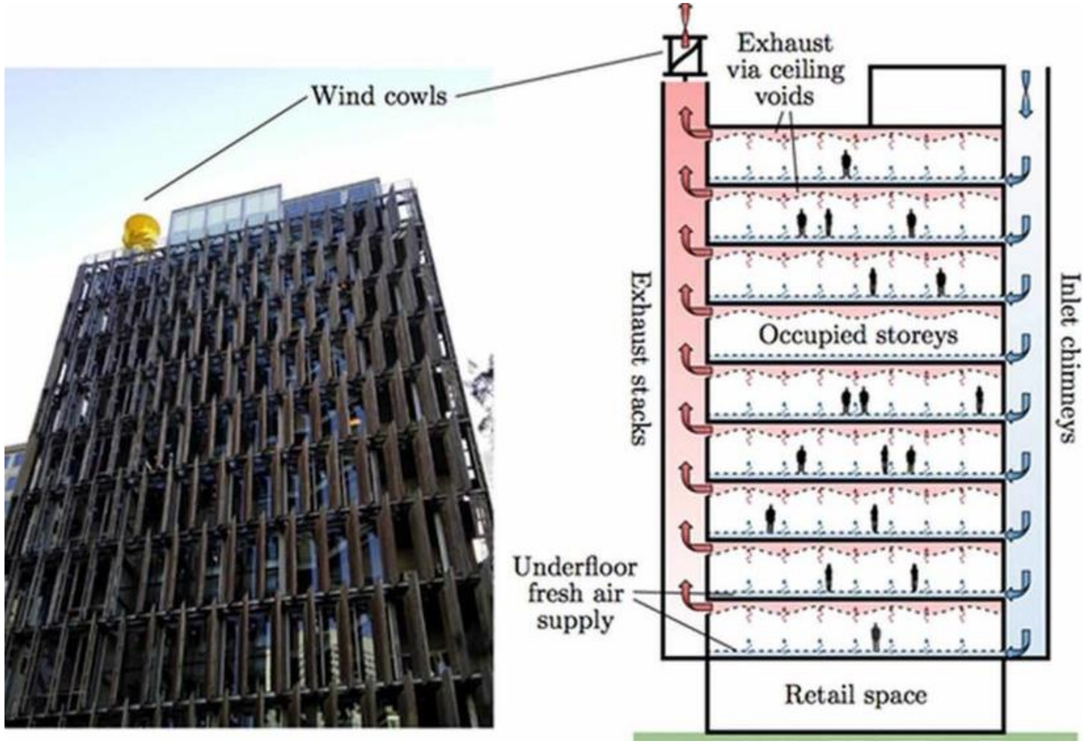


Figure 88 CH2 Building.

Source: CH2 Building. - Bing images

Fig. 89 Image showing the map of Africa with Zimbabwe in context.

Source: WorldAtlas.com, 2022

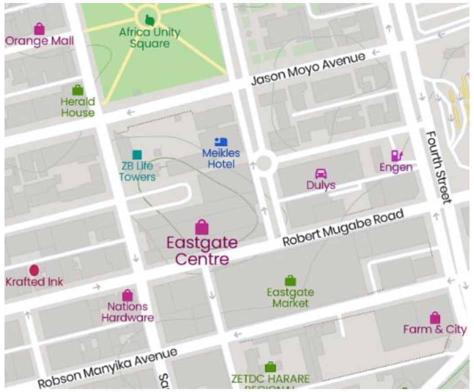


Fig. 90 Image showing the location of East Gate Harare, Zimbabwe.

Source: Eastgate Centre - Map - Mapcarta, 2023

Case Study 03: East Gate Building Harare, Mick Pearce

The Eastgate Centre, a nine-story mixed-use structure with parking, retail space, and office space located in Harare, Zimbabwe, lacks an operational HVAC system. Using termite mounds as inspiration, the architect created a system for ventilation that pulls and pushes heated air into the flues at the peak of the tower.

The design of the Eastgate Centre strays intentionally away from the "big glass block." Since they need plenty of heat in winter as well as cooling in the summer, glass office buildings are frequently expensive to maintain comfortably. They routinely recycle air to keep the expensive temperature control in place, which increases the building's pollution levels. Artificial cooling systems need a lot of upkeep, and Zimbabwe also has the problem of having to acquire the initial setup and the majority of spare components, depleting its foreign exchange reserves in this process.

A daily temperature range of 10 to 14 degrees Celsius is normal for Harare's moderate climate. Mick Pearce used a different strategy to cool the structure.

Ove Arup carried out computer simulation and analysis and gave Pearce some guidelines. These rules were:

1. The North façade's exterior walls cannot receive direct sunlight (summer sun's orientation).
2. The maximum window-to-wall area is 25%.
3. An equilibrium between interior and outside lighting to reduce energy use and heat gain.

Fig. 91 Image showing East Gate Harare, Zimbabwe.

Source: eastgate-2a-600x767-40.jpg (600×767) (mickpearce.com), 2023

4. Due to noise pollution, fluctuating wind speeds and temperatures, and the need for ducted ventilation, every window must be shut.

5. Windows must serve as light filters above everything else, reducing glare, noise, and privacy.

Mick Pearce took inspiration from the building of the termite colony. The tower of termites serves as a lung. Smaller openings on the edges of the termite's nest allow cold air to enter while hot air rises. The tower is shaped by wind and sun. The termites only operate in protected regions since the southeasterly daytime breeze dries off the scents on the surfaces that are the most exposed. Termite mounds regulate the environment by employing the thermal mass of the earth, the diurnal variation in outside temperatures, and moisture from the groundwater table beneath to maintain a constant, low temperature. This is Eastgate Harare's guiding concept.

Fig. 93 Image of a termite mound.
Source; Author, 2021

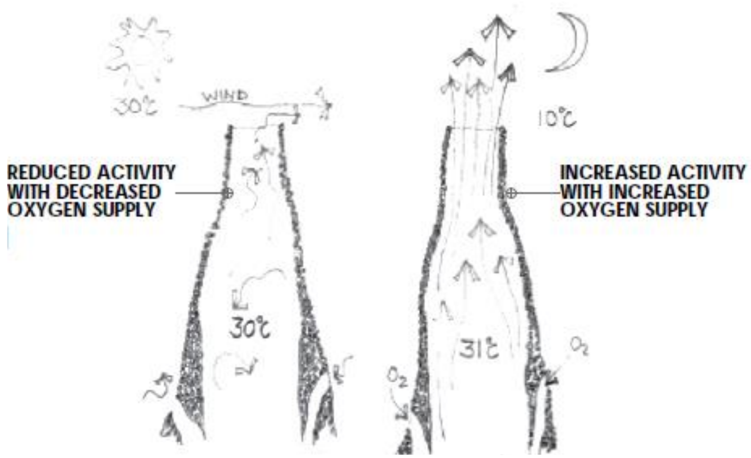


Fig. 92 Image showing how the day and night cycle drives biological activity in the termite nest.
Source; Author modified.

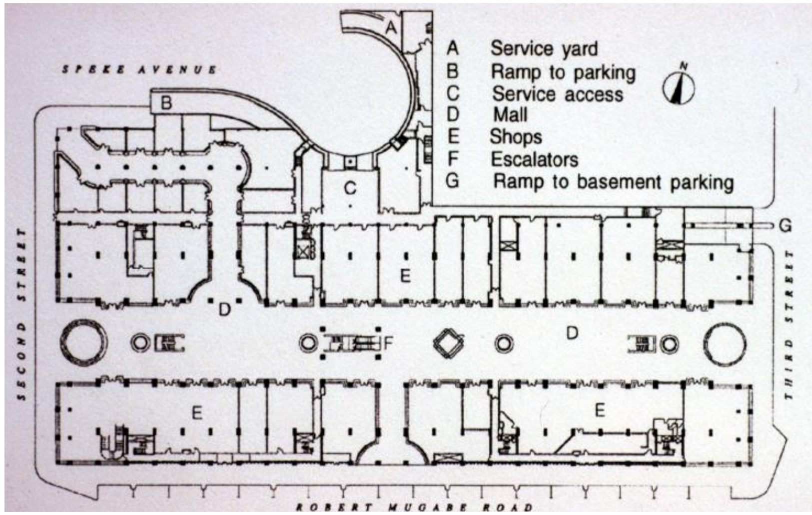


Fig. 94 Image showing the Ground floor plan on East Gate Harare.

Source: :EAST GATE HARARE (ZIMBABWE) by Shiva Shankar (prezi.com), 2023

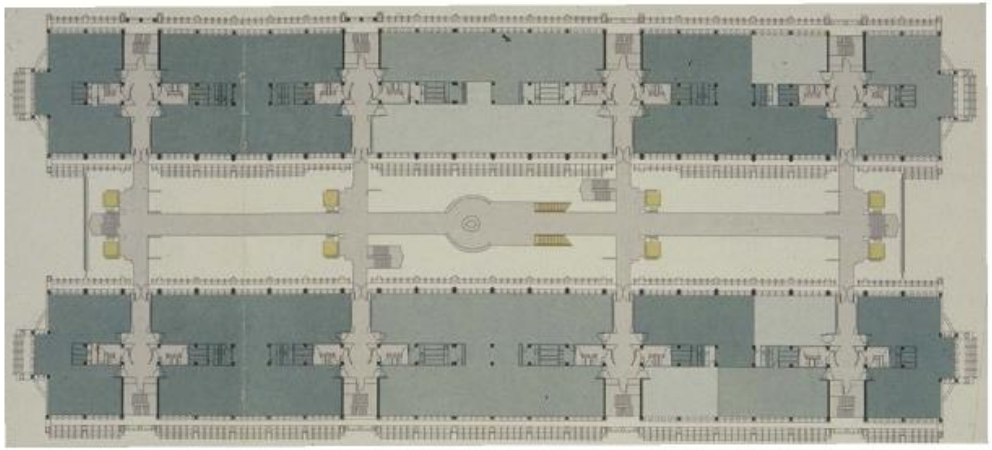


Fig. 95 Image showing the office floor plan of Eastgate Harare.

Source:: EAST GATE HARARE (ZIMBABWE) by Shiva Shankar (prezi.com), 2023

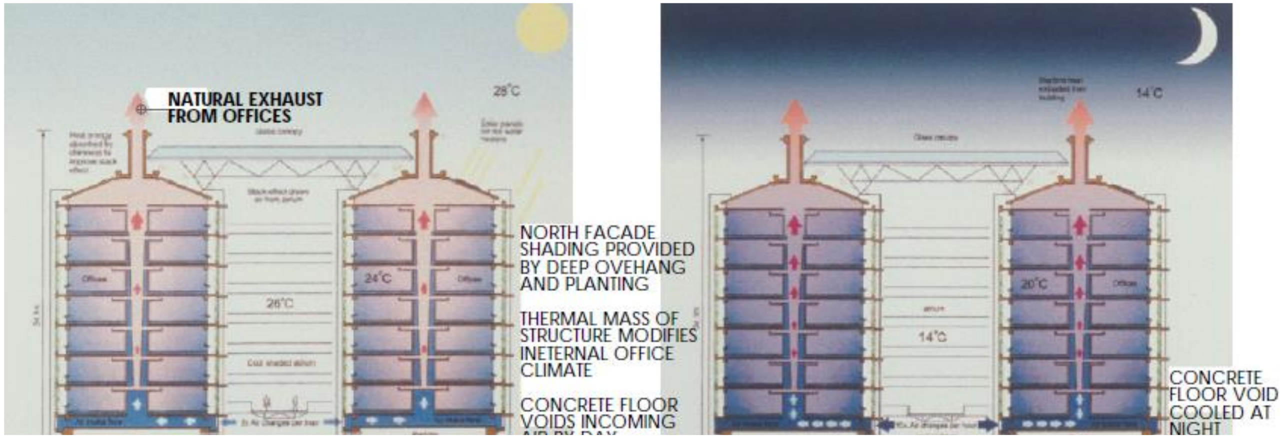


Fig. 96 Image showing the showing of Eastgate Harare, illustrating day and night ventilation.

Source: EAST GATE HARARE (ZIMBABWE) by Shiva Shankar (prezi.com), 2023

Fig. 97 Image showing Eastgate Harare.
Source: Eastgate-Centre-in-Central-Harare-Zimbabwe.jpg (650×488) (eaconstructionsdigest.com), 2023

Fig. 98 Image showing Eastgate Harare.

Source: 2df58d2e61a40663837571ec13a12110.jpg (236×248) (pinimg.com), 2023

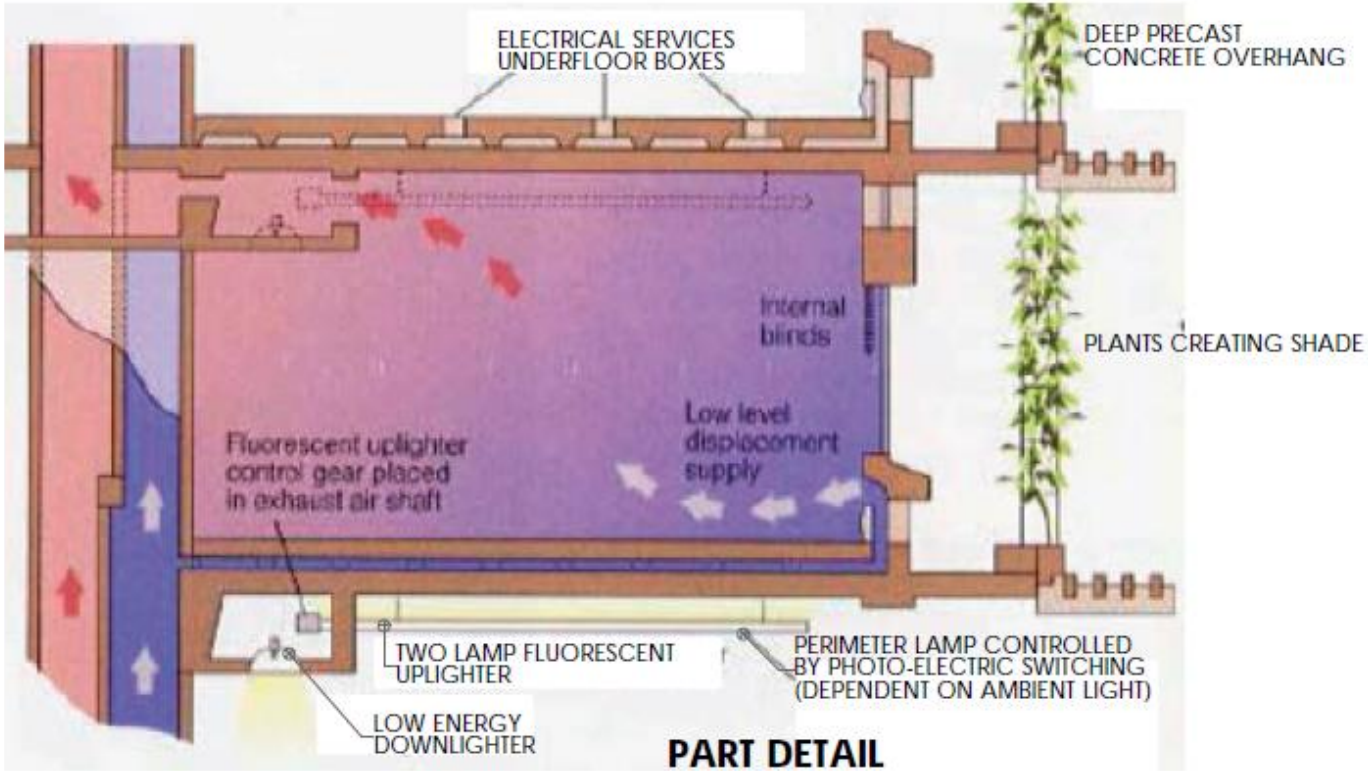


Fig. 99 Image showing construction part detail of Eastgate Harare.

Source: Case Study: EAST GATE HARARE (ZIMBABWE) by Shiva Shankar (prezi.com), 2023

Figure 100 Interior image showing Eastgate Harare.

Source: eastgate02.jpg (504×753) (cargocollective.com)

For energy efficiency, it includes a façade with specially constructed sun breakers to block off direct sunlight between the hours of 9 am and 5 pm.

Windows lessen the impact of the weather by minimizing the demand for cooling on the office levels by 75%. Before entering the room, the air flows through precast concrete floor units, which act as heat exchangers and remove the coolness accumulated from the previous night.

In summary, East Gate Building, Harare, has employed more passive and energy-efficient mechanisms of climate control. This design borrows heavily from nature by observing patterns and analysing them and bringing those patterns into the design. The following bioclimatic strategies have been applied in the project;

1. Use of thermal chimneys to extract air
2. Use of solar panels for water heating
3. High thermal mass
4. Use sun-shading screens, deep overhangs, and plants to create shade.
5. Use of atrium
6. Glass roof with open sides for ventilation
7. Light filters above all windows control glare and noise

2.6 Glass-cladded Buildings in the Tropical Climate

Figure 101 Image showing Lonhro House; a glass-cladded building in Nairobi.

Source: Author, 2023

Glass has been used in construction since approximately 200 years ago (Knaack, 2008; Mocibob, 2008). In contrast, the employing of glazing in tropical climates lacking consideration of scientific investigation of each of the glass properties used, type, colour, thickness, and the idea of using facades made of glass that is different from the inside and outside building spaces in European countries pertains to the physical characteristics of glazing and their effect on the interior surroundings of buildings, performing as insulation against hot or cold temperatures, the wind, and noise. To maximize natural illumination inside buildings without compromising thermal comfort, glass should be employed. Glass facades are a common feature of buildings and act as a barrier separating the interior and outdoor atmospheres. Designers of energy-efficient buildings have consequently started to base their study on this subject. Energy use in buildings has developed into a serious issue as a result of the restricted energy sources that are now accessible. Glass and other building construction materials should thus be taken into account throughout the planning phase.

The performance of glass facades is governed by four main principles. A glass façade on the building's envelope separates the inside environment from the exterior environment. Environmental burdens are produced by differences between the two environments. These environmental loads can be divided into three categories: temperature, moisture, and air pressure. Temperature load is influenced by both interior temperature variables, such as human activity, airflow, and heating devices, as well as outer temperature components, such as outside air temperature, sun radiation, and wind. Glass should serve three major purposes, including:

i. carrying wind load,

ii. visual comfort,

Figure 102 Image showing the I&M Building a glass cladded building in Nairobi.

Source: Author, 2023

When a person's eyes are properly lighted, they are able to perform tasks that are directly tied to the amount of natural or artificial light available in the surroundings. This situation is known as visual comfort. primary determinants of visual comfort Users must be able to observe items logically, comfortably, and in visually appealing tones in the visual environment. The visual comfort variables for which designers play a dominant role are the level of light for visual activities, the compatible distribution of light inside a space, the proportions of light within buildings, the lack of undesirable shadows, an outside view, good colour comprehension, pleasing tones of light, as well as the lack of glare. Human performance and visual comfort: Lighting quality is one of the factors that affect how well people perform indoors. Numerous studies have been conducted to study the impact of various types of lighting on health, efficiency, well-being, and attention level. The two most important aspects of light to consider when it comes to human perception are correlated colour temperature (CCT) and illumination level.

iii. and thermal comfort

24 to 26 degrees Celsius is the recommended range of temperatures for thermal comfort. The body's surface temperature, however, is between thirty-three and forty-four degrees Celsius while inactive, whereas internal temperatures increase as activity levels do. Temperatures exceeding 45 degrees Celsius can permanently damage the brain, while temperatures of less than 18 C can cause major cardiac arrhythmia and death. Therefore, it is crucial to properly control body temperature for comfort and health.

Figure 103 Image showing the Anniversary Towers building.

Source: Author, 2023

The glass facade is significantly influenced by Significant factors that affect the glass facade include In tropical climes, there are often three primary issues that buildings must deal with in terms of thermal comfort. These include high relative humidity, high temperatures gain in warm seasons, and extreme loss of heat in cold seasons. Buildings in these temperate zones need plenty of energy, therefore maintaining a pleasant temperature for residents is expensive.

Natural ventilation works because of two things: wind and buoyancy. Changes in wind pressure and interior and outdoor temperature cause natural air exchange between exterior and interior units along the building exterior.

In addition, passive natural cooling generates energy by using the airflow from the outside to ventilate and cool the structure without the need for fans or other driven mechanical equipment. There are some scenarios whereby the same ideas may be applied to existing structures, yet passive cooling techniques are often utilized in the construction of new structures.

Solar radiation raises the surface temperatures of glass facades, which increases drying rates and inward vapor flows. Radiation travels in a straight line between two surfaces. With the aid of the sun's path and the building's orientation, it is now simpler to predict the position, timeframe, and level of solar radiation.

The solar radiation that penetrates the planet's surface is composed of two components. These are the direct and diffuse beams of sunlight. There are many different gaseous components in the air that surrounds the earth, as well as suspended dust alongside other liquid and solid particles. Due to reflection, refraction, diffraction, or absorption, the solar light is altered.

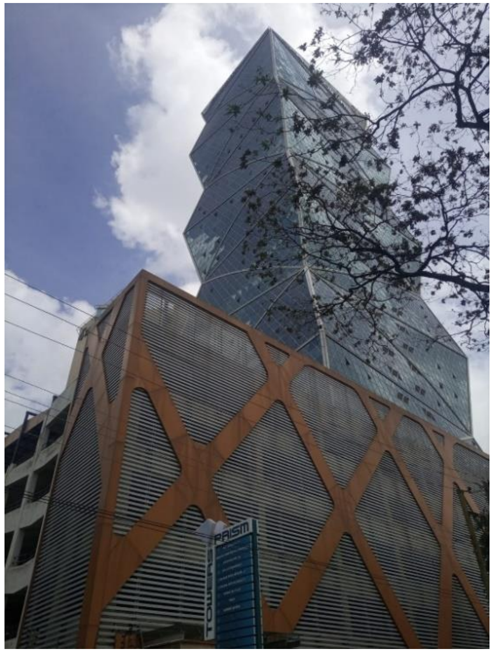


Figure 104 Image showing Prism Towers building. Source: Author, 2023

Thermal transmittance, sometimes referred to as the U-value, is the unit of measure used to describe how well heat is transferred through building materials. It is represented in W/m2 K. The U-value is a measure of loss of heat per square meter for a temperature difference of a single Kelvin or degrees Celsius between the inside and outside surroundings divided by the glass. R-values, often known as thermal resistance, are another approach to calculating heat loss. R = 1/U-value or R = m2 k/w.

The quantity of solar radiation that travels through an exposed façade of a structure is determined by the amount of energy available, the area, direction, and heat transmission characteristics of the exposed façade. Through glazing, as much as 85% of the incoming radiation may be obtained from the sun. The thermal efficiency of a glass building is influenced by its shading coefficient. The value demonstrates how the glazing is thermally shielding (shading) the inside when you have direct sunlight on the facade or window. Its value ranges from 1 to 0.00. Reduced solar heat transfer ratings boost the glass's ability to block sunlight.

Glass due to its properties has negative effects when used in buildings. These effects include the price of security increases due to the use of glass. It is also dangerous in areas that have experienced earthquakes. Glass does a poor job of retaining heat, which increases the expense of running air conditioners, and acts as a greenhouse by absorbing heat, making it unsuitable for hot and humid areas. There will be greater energy consideration for air conditioning and an increase in A/C demand. Figures 103 and 104 show two glass buildings in Nairobi. Glass, however, has the following advantages

Figure 105 Image showing One Africa building tower. Source: Author, 2023

- Use of glass adds beauty to the building. It makes it more aesthetically pleasing.
- Installation of glass ensures an ample supply of natural daylight which makes the construction more sustainable
- Glass tends to have great weather resistance. It shows no significant loss of quality due to exposure to the weather conditions throughout all the seasons
- Unlike metals, which are also used in building construction, glass does not rust by exposure to humidity and air.
- Cleaning of glass is easy when compared to other building materials
- Usage of glass ensures passage of natural light even when the doors and windows are closed
- Glass can be produced in shades of different colours, adding to its inherent aesthetic features and making it more artistic.
- It may take any shape by being blown, drawn, or pushed.
- Due to its complete transparency, it offers the best manner to present a product.
- Glass may be recycled indefinitely without losing its quality or purity because it is 100% recyclable.
- Glass is an excellent insulator against electricity.

2.7 Occupancy Levels of both Bioclimatic energy-efficient Buildings against glass-cladded Buildings

Several ideas that have been put up to explain the earnings premiums which Leadership in Energy and Environmental Design, or LEED, and Energy Star buildings can earn (Eichholtz, Kok, and Quigley, 2010, Fuerst and McAllister, 2011, et Das and Wiley, Inc. 2013).

A growing body of research shows that green buildings benefit society, the environment, and the economy in several ways, including lower operating costs, higher employee productivity, tax credits, and a better reputation among the general public (Fuerst and McAllister, 2011, p. Kok, Miller, and Morris (2012) found that the rental premium for LEED-certified buildings is 7.1% greater than for non-certified buildings. Furthermore, their analysis shows that homes with both LEED and Energy Star certificates fetch higher rents. A 5% rental premium for buildings that are LEED-certified and a four percent discount for Energy Star buildings are suggested by Fuerst and McAllister (2011). As a result of greater levels of certification, they also discover a twenty-five percent discount for buildings with LEED certification and a twenty-six percent discount for Energy Star-certified buildings in regards to sale pricing.

Reichardt, Fuerst, Rottke, & Zietz (2012) track a rental discount for buildings having the Energy Star and LEED licensing throughout the period 2000–2010. The data indicates a significant rental premium for both green-certified buildings steadily increased from 2006 and 2009, with a slight decline after that year as a consequence of the "great slump" economic crisis. Two research investigations that show how premiums change over time, among diverse size groups, and in different geographical areas are Das & Wiley (2013) & Robinson and McAllister (2015). To account for any regional economic variations, this analysis adopts Crone's (2005) categorization of economic zones based on their common industrial and social features. This is favoured over other approaches and U.S. census regions since it is more recent and allegedly a better predictor of contemporary economic links (for example, Malizia and Simons' Salomon Brothers configuration from 1991).

Many business premises tenants also use buildings as a forum to advertise their environmentally friendly views, in keeping with a green or sustainable corporate strategy. CSR (corporate social responsibility) guidelines can compel tenants to benefit from green buildings in ways other than those that directly benefit the tenants' businesses (Eichholtz, Kok, & Quigley, 2009). Recent research has shown that consumer sentiment and tenant preferences might affect real estate prices (Marcato and Nanda, 2015).

The leasing arrangement may also affect who benefits from environmentally friendly construction utility expenses (owners vs. tenants) (Jain & Robinson, 2015).

Tenants under a Triple Net (NNN) lease arrangement, where utilities are in extra to base rent, may be convinced to pay an additional fee in exchange for the usage of particular cost-saving facilities.

However, building owners, who immediately benefit from those cost-saving measures since they bear all utility expenses under a Full-Service Gross (FSG) lease, wonder if tenants would be prepared to shoulder them under this arrangement. In the world of commercial real estate, the subject of leasing premiums has gained more attention (Liu and Liu, 2013). In addition to empirical investigations on the green premium, most research examines how public policies affect market uptake of green buildings.

In their 2009 article Simons, Choi, and Simons, the authors demonstrate the influence different public policies have on the green building sector. For instance, their study shows that executive orders are a speedier approach to encouraging green development than laws.

BIOCLIMATIC BUILDINGS						GLASS-CLADDED BUILDINGS				
Building	Architect	Location	Year built	No. of Floors		Building	Architect	Location	Year built	No. of Floors
Chai House	Hughes and Polkinghorne	Koinange Street	1962	11		Cooperative Bank Headquarters	Zevet Kenya Architects	Haile Selassie Avenue	1981	23
IPS Building	The Architects Collective (TAC)	Kimathi Street	1967	13		Lilian Towers	Symbion International	University Way	1984	13
International Life House	Dougliesh Marshall and Johson	City Hall Way, Mama Ngina Street, Simba Street	1971	17		Lonhro House	James Archer of Planning System	Kaunda Street, Standard Street	1990	22
680 Hotel	Dougliesh Marshall and Johson	-	1972			AmBank House	Arch. Wambaa Mungai	Monrovia Street	1991	21
Uchumi House	-	Aga Khan Walk	1972	23		Anniversary Towers	-	University Way	1992	26
KENCOM House	Vamos and Partners	Moi Avenue	1973	10		Afya Centre	-	Tom Mboya Street		21
KICC	Karl Henrik Nostvik and David Mutiso	City Square	1974	10		View Park Towers	Harban Singh Architects	Monrovia Street		22
Electricity House	City Hall Annex	Harambee Avenue, Aga Khan Walk	-	23		I &M Bank Tower	Planning System Services Ltd	Kenyatta Avenue, Banda Street	2001	18
St. Georges House	Hughes & Polkinghorne	Parliament Road	1975	6		Delta Tower	Innovative Planning & Design Consultants	Waiyaki Way	2012	21
NHC House	-	Harambee Avenue	1975	14		Kings Prism Towers	-	3rd Avenue Ngong Upper Hill	2018	34
Rehani House	Mutiso Menezes International	Koinange Street	1976	13		Britam Tower	GAPP Architects & Triad Architects	Hospital Road, Upper Hill	2018	31

National Bank	Richard Hughes	Harambee Avenue	1976	20
KPCU Ghala 1	Triad Architects	Haile Selassie Avenue	1978	7
Treasury Building	Mutiso Menezes International	Harambee Avenue	1980	15
Norfolk Towers	Triad Architects		1978	
Maendeleo House	-	Loita Street	1980	11
ICEA Building	Richard Hughes	Kenyatta Avenue	1981	19
BIOCLIMATIC BUILDINGS				
Building	Architect	Location	Year built	No. of Floors
Nyayo House	Ngotho Architects	Kenyatta Avenue	1982	
Shell & BP House	Christopher Archer	Harambee Avenue	1981	7
Chester House	Covell Mathews and Partners	Koinange Street	1984	19
Nyati House	-	-	1984	8
Kenindia House	Douglesih Marshall and Johnson (DMJ)	Loita Street	1984	16
Postbank House	Waweru & Associates	Banda Street	1985	11
Ecobank Towers	James Archer	Muindi Mbingu Street	1985	21

One Africa Place	BAA Architects	Westlands	2019	22

Table 3 List of Bio-climatically Designed and Glass cladded Building in Nairobi. Source: Author, 2023

Figure 106 Image showing the aerial view of Nairobi CBD from the Hilton Hotel.

Source: OIP.faAEoHttDZ1FAz3Pn9mIbgHaEy (474×306) (bing.com)

Figure 107 Image showing the aerial view of Upper Hill Nairobi.

Source: DjuvfQwX4AAvOJx.jpg (1200×900) (twimg.com)

2.8 Literature Review Conclusions

This chapter sets with an introduction. The development of green buildings is emphasized throughout history. It has been examined how man has been able to harness and change natural processes throughout history to better his way of life. Additionally, the 20th century has been covered, along with the methods and creations that led to the development of several systems seen in modern structures and the era in which high energy consumption first appeared. Some of the most significant developments in the construction industry include the creation of electrically operated air-conditioning units, the adoption of innovative building supplies like reinforced steel and concrete, and the development of the lift, which inspired the construction of multi-story buildings.

The effects of the oil shortage of 1973 led to the requirement for energy-efficient building design. Energy-efficient buildings should be planned with attention to the complete life cycle of the construction project to minimize environmental effects, save operational costs, and promote sustainability. An analysis of the tropical environment was conducted, and examples of bioclimatically built buildings were contrasted with glass-clad structures, which are seen as appealing but challenging to build in tropical areas. The aerial is seen in Figures 104 and 105.

In conclusion, a balance between visual appeal, environmental sustainability, and occupant comfort must be achieved in order to guarantee the long-term viability of any building project. The mechanisms that have evolved along with the concept of a "green building" have made it possible to grade buildings in line with green building standards. Buildings are certified at various levels following this (Celebi et al. 2008).

03: RESEARCH METHODOLOGY

Chapter Three

3.0 Introduction

Figure 108 Image of AMBAK Nairobi. Source: 4356148403_7eab0c0c8c_b.jpg (684×1024) (flickr.com)

The definition of research given by Grinell is "an organized study that utilizes established scientific methods to solve a problem and develop fresh and meaningful knowledge" (Grinell, 2014). For this, it is necessary to work systematically with ideas and tactics which have undergone significant validity and reliability testing. Validity depends on the suitable approach, but reliability is defined by the method's ability to provide comparable results when repeated (Kumar, 2005).

This chapter outlines the methods of study to be used in Nairobi CBD and its environs. It emphasizes data collection methods and sources that are used in the field by the author. The reasons for each method, how it was implemented, and the purpose of the analysis method are briefly explained. This research aimed to document both glass-cladded and bioclimatic buildings in Nairobi CBD – in terms of their occupancy levels and energy efficiency. Figure 106 shows AMBAK a glass cladded in Nairobi.

The aim of the study, design, strategy, sampling criteria, demonstrable qualities, and observable variables, data collection, analysis of data, and presentation are outlined in this chapter. This is aimed at reaching the objectives and targets set out in chapter one, and also listed below:

Figure 109 Image of the Citadel building Nairobi. Source: 2209274414_a6023cca18.jpg (334×500) (flickr.com)

1. To establish existing knowledge on the energy efficiency of bioclimatic buildings in tropical climates with a focus on Nairobi.
2. To investigate the energy performance and occupancy levels of glass-cladded buildings and bioclimatic buildings in Nairobi.
3. To make recommendations for guidelines and strategies that can be developed for buildings in Nairobi to make them energy efficient

3.1 Research Purpose

The goal of this research is to document both glass-cladded and bioclimatic buildings in the CBD their occupancy levels and energy efficiency. The guiding principles for the study were these research questions;

1. What is the existing knowledge on energy-efficient bioclimatic buildings in tropical climates with a focus on Nairobi?
2. What is the occupancy and energy performance of glass-cladded buildings and bioclimatic buildings in Nairobi?
3. What guidelines and strategies can be developed for buildings in Nairobi to make them energy-efficient?

To explore the research problem in detail, the existing glass-cladded and bioclimatic buildings are investigated through a comprehensive analysis of their energy efficiency and occupancy. Data collection was undertaken from a representative sample of buildings within the CBD, Upperhill, and Westlands to inform this study.

Figure 111 Image of Oval Building in Westland's Nairobi.
Source; R.b0ee427c355a4ff17850be24aad140b9 (826×600) (bing.com)

Figure 110 Image of EcoBank Nairobi.
Source: VGxk9kpTURBXy80OGIxYjQ4YjlmOTJjNWZlMDRjYmNmZDU4MWFjNTliMi5qcGeQgaEwAA (860×645) (ocdn.eu)

3.2 Research Design

According to Mugenda (2012), a research design is a framework, strategy, and plan created to address research issues. Research design often refers to the overarching research techniques of the study (Groat & Wang, 2002).

There are three categories: Explorative, Explanatory, and Descriptive. This research is descriptive as well as explorative since descriptive research helps to analyse the factors that affect the form, while exploratory research helps to find alternatives for a solution.

A variety of data sources, including observation, interviews, design, and measurement, were used in this study to strengthen the analysis.

3.3 Research Strategy

Three research methodologies exist experiments, surveys, and case studies: -Mugenda & Mugenda (2012). This study used a case study approach to its investigation. The goal of the case study method was to offer a thorough analysis of a phenomenon, incident, or event in the context of real life. According to Mugenda & Mugenda (2012), a case is a system with boundaries containing components that interact. Therefore, a case may be a system that is made up of an individual, a company, a community of people, or some other type of organization. A case study research methodology produces a comprehensive, multi-layered knowledge of a challenging issue in its practical setting. (Crowe, 2011).

Data gathering and analysis for this study used qualitative and quantitative methods. The act of gathering, analyzing, and interpreting non-numerical data, such as text, drawings, videos, and pictures, is known as qualitative research. The focus of quantitative research methods is on objective evaluations of the data acquired by statistical, mathematical, or numerical analysis (Rukwaro, 2016). To run energy efficiency, the case study region was also designed employing Revit and ArchiCAD software. The finest opportunity to contrast and examine similarities or differences is provided by this method

3.3.1 Sampling Design

This refers to the process or techniques used to select a suitable sample or a representative part of a population for the determination of population parameters or characteristics (Mugenda and Mugenda 2012). Considering the limited time available to carry out the research, Purposive sampling was used to select the buildings in the CBD and its environs.

3.3.2 Area of study

The area of study is Nairobi CBD and its environs. This area was chosen because of the rise of glass-cladded buildings. There is also a good number of bioclimatic buildings. Population: the study focuses on the bioclimatic and glass-cladded buildings in the CBD and their environs, their energy efficiency, and occupancy. Sample size; a total of thirty buildings were assessed to determine their occupancy levels and monthly electric consumptions. Of the thirty buildings, three were chosen on the availability of building plans and ranging from glass-cladded to bioclimatic buildings were modelled for energy simulation and analysis of their energy efficiencies.

Figure 112 Image showing Laser Distance Meter.
Source: Author, 2023

Figure 113 Image showing NIKON camera.
Source: Author: 2023

3.3.3 Time horizon

In this study, data were gathered via cross-sectional investigations. The analysis was done in January and February 2023. Field activities involved taking measurements of both glass cladded and bioclimatic buildings, taking photographs and sketching the layout and sections, and conducting interviews with building users.

3.4 Data Collection

3.4.1 Data from both secondary and primary sources were collected. Leeds (1993) defines data collection methods as the act of administering research tools. The primary and secondary sources of information are collected. In case-study research, participant and non-participant observations, informal interviews, and content analysis of significant documents, experiences, and events that took place during the research period are all used to collect data (Mugenda & Mugenda, 2012). Primary Data Sources. Figures 112 and 112 shows some equipment used during data collection.

3.4.2 Interviews

Structured and unstructured interviews were conducted in Nairobi CBD about the energy efficiency and occupancy of bioclimatic and glass-cladded buildings. I would encourage those interviewed to share their feelings, opinions, and beliefs regarding energy efficiency in buildings, are bioclimatic buildings more comfortable to live and work in compared glass-cladded buildings? The interview contains clear questions for building owners and consumers. The questions were intended to influence the course of the discussion and in particular occupancy and energy efficiency in buildings.

i. Observation

Both participant and non-participant observations are considered in the observation process. Participant observation was nonetheless employed in this study. By immersing individuals directly in the environment, participant observation serves as a key research tool to get a close and personal understanding of a particular subject of study. Techniques of observation included;

1. Free-hand sketching
2. Photography
3. Taking notes of key observations

ii. Sketches, Photographs, and Measured drawings

Photographs were taken to document the architectural forms as they currently exist, as well as how they react to their immediate surroundings, how spaces are used, the materials used, and more. Along with images, free-hand drawings were employed to depict constructed shapes. Sketches were also used to enable the author to rapidly capture objects and record the plans and elevations measured.

Figure 114 Image of Delta Chambers building, in Westlands, Nairobi. Source: R.9593f491a537ce360540a9f871ac82fd (750×450) (bing.com)

iii. Modified 3D Images and Visualization

The study of shape and structure, along with selected environmental variables, was carried out using updated 3D images and visualizations, and computerized models. ArchiCAD 25 and Revit 22 were used to build them.

Figure 115 Image of Delta Chambers building model.
Source: Author Modified, 2023

3.4.3 Secondary Data Sources

i. The literature review; was discussed primarily in chapter two. The study examined the development of energy-efficient buildings over the past century and the need of taking into account a building's life cycle when constructing an energy-efficient structure. Pre-building energy-efficient design methods, building-phase energy-efficient design strategies, and post-building energy-efficient design approaches. Bioclimatic architecture is covered, as well as glass-cladded buildings in tropical climates, occupancy of both bioclimatic energy-efficient buildings and glass-cladded buildings, and the chapter's conclusion. The literature review emphasizes the research topic and provides the overall direction while providing an explanation of conceptual sceneries and general notions.

ii. Information from the Local government, local meteorological stations and building managers, caretakers, and owners. They include maps, fieldwork areas, case studies plan, and climate-related data.

3.4.4 Materials and Methods

The study comprises two sections:

1. Occupancy and energy efficiency from field survey matrix.
2. Energy Efficiency simulations and analysis

Figure 116 image of Nation Centre, Nairobi CBD. Source: OIP.qSPrSbXNDiJSwZ_oS9nuNQHaLE (474×708) (bing.com)

The study to be carried out on occupancy per square meter was carried out on several buildings. The occupancy levels were assessed by determining the number of people per m2 of rentable area. Simulations were done on three buildings. The selection of buildings is purposeful due to the limited time to carry out this research. Energy analysis will be derived from the bills provided by the building's management or Kenya Power Lighting Company for the year 2022. The available plans of buildings will be used to get the areas and modelling the buildings for simulations.

To determine the energy efficiency of the structures, energy intensities were calculated using monthly power usage bills for 2022 and compared to the Benchmark and Baseline established by the Energy and Petroleum Regulation Authority (EPRA) in 2012. Equation 1 provides the building energy intensity.

Eq. 1 $n=E/A$

n= this is the Building Energy Intensity (BEI)(kWh/m2)

E=Total Energy Consumption by a building

A= total area of the building

3.5 Data Analysis

Figure 117 Image of Nation Centre Building. Source: Author Modified, 2023

Data analysis requires data collection, interpretation, and manipulation, into useful knowledge that can help you draw conclusions and guidance, (Alexandre et al., 2008). This represents data gathered during fieldwork research to help reach conclusions and recommendations

The study of data is structured to extract knowledge to address questions about research. In the case of qualitative study, raw data is cleaned up and sorted for content analysis in particular classifications to produce descriptive data. The descriptive analysis thus supports significant statistically-oriented findings (Rukwaro, 2016).

In this study, qualitative as well as quantitative data were gathered. Data from the quantitative analysis was used to create graphs and charts, from which comparisons, inferences, and suggestions could be made. To develop graphs and layouts with energy efficiency considerations, data was created employing the Climate Consultant Software and REVIT BIM software. Written descriptions and analytical drawings are used to analyse the qualitative information acquired from observations and interviews. Fig. 117 shows Nation Centre Building to be model simulated and analysed.

The data was analysed and presented to address the issue of occupancy levels and energy efficiency of glass-cladded and bioclimatic buildings in the CBD and its environs. A comparative analysis of occupancy and energy efficiency was done.

3.6 Data Presentation

The following sections describe the various techniques used to present the analysed research findings to enhance legibility and ease of understanding of the research findings.

3.6.1 Charts / Graphs

Graphs will be used to convey most of the findings of this research and to accurately capture and explain the conditions in the field.

3.6.2 Descriptive.

Words were used to convey some of the findings of this research and to accurately capture and explain the conditions in the field.

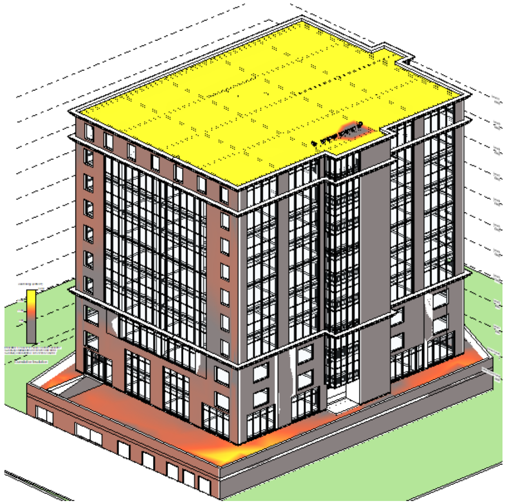


Figure 118 Image of Delta Chambers Solar study model. Source: Author, 2023

3.6.3 Sketches and Drawings

Sketches were used to present layouts, sections, elevations, and details captured in the field CAD and BIM software were used to enhance some of the sketches for better understanding.

3.6.4 Photography.

Photos have been used to give a true representation of what is on the ground: building components, form, and other details will be photographed to give a deeper understanding and to enforce description of various phenomena which is hard to put into words.

3.6.5 Maps

Maps were used to accurately indicate the location of the area of study and to show the specific building that has been studied.

3.6.6 Table

Tables will be used in the analysis. Tabulated data allows for simple comparison. They are used to convey textual and graphical information allowing for comparisons to be made between the buildings. This method presents a summary of the findings for each case study allowing for conclusions to be drawn.

Figure 119 Image of Nation Centre Solar study model.

Source: Author, 2023

3.7 Summary

In this chapter several issues were discussed, the author first reiterates the research questions and addresses the research design, time horizon, and sampling methods used in the collection of case studies. The author then describes the scope of this analysis and further examines the purpose of collecting and reporting the information in detail. During the field study, the methods of collecting and reporting data are applied.

Table 4 shows the summary of parameter and variables employed

PARAMETER	VARIABLES ASSESSED	DATA SOURCES AND COLLECTION METHODS	DATA ANALYSIS METHODS
1. Climatic Data	• Temperature • Radiation • Sky cover • Illumination • Relative Humidity	Nearest Meteorological Departments – Nairobi Wilson Airport	1. Simulation analysis 2. Use of Graphs and Charts
1. Suitable site selection 2. Site plans 3. The form of building 4. Building layout and appropriate space organization 5. Envelope of the Building 6. Choosing energy-efficient building materials 7. Landscape design that is energy-efficient 8. Application of renewable energy resources: 9. Occupancy	Part A Dependent Variable 1. Mean Annual Energy Use Independent variable 2. Building area 3. Percentage of occupancy 4. Rent per m2 per year Part B: Energy Simulation 1. Building orientation 2. Window Wall Ratio 3. Window shades 4. Infiltration 5. Lighting Efficiency 6. Plug load Efficiency 7. Daylighting & occupancy control 8. HVAC 9. Wall and roof construction 10. Operating schedule 11. PV-Panel Efficiency	1. Primary data: i. Interview ii. Observation iii. Sketches, photographs and measured drawings iv. Computer Simulation 1. Secondary data i. Literature review, ii. Local metrological	1. Photographs, Sketches, and architectural drawings 2. Computer modelling and Simulation analysis 3. Graphs 4. Visual analysis 5. Comparative analysis

04: FINDING AND ANALYSIS

Chapter Four

4.0 Introduction

4.1 Area of Study

4.2 Nairobi Climate Analysis

4.3 Case Study Analysis with Occupancy and energy consumption of Buildings

4.4 Energy Efficiency by Simulation of Buildings

4.5 Applied Methodology for Energy Simulation

4.6 Case Study Analysis by Simulation

4.7 Summary

Figure 120 map of Africa showing Kenya in context.

Source: Author, 2023

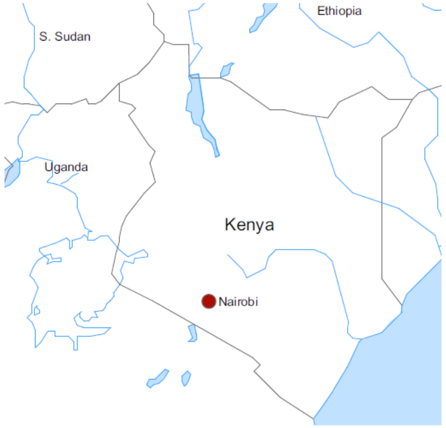


Figure 121 map of Kenya showing Nairobi in context.

Source: Author, 2023

4.0 Introduction

Nairobi, Kenya's capital city, is home to the central business district (CBD), which acts as the commercial and economic hub of the area. The British colonial government chose Nairobi as the stopping place for their railroad that would run from Mombasa to Uganda in 1899.

Nairobi started to expand quickly as a result of the railway's construction, which attracted lots of workers and residents to the region. A new metropolis was envisioned after the town was designated as the capital of British East Africa in 1900. Figures 120 and 121 show Nairobi in the context of Africa and Kenya respectively.

Early in the 20th century, the first buildings in the CBD were built, most of which were made of wood and iron. A fire in 1913 destroyed a large portion of the town, including the majority of the CBD's structures. Several of the new structures in the reconstructed town are composed of stone and brick.

The CBD served as Nairobi's hub of political, social, and commercial activity during the colonial era. The CBD was where the majority of the city's offices, banks, and stores were situated. After Kenya won independence in 1963, the CBD kept expanding and changing with new construction and infrastructural initiatives.

Today a thriving commercial district featuring skyscrapers, offices, hotels, banks, civic buildings, restaurants, and stores can be found in Nairobi.

4.1 Area of Study

Figure 122 Image showing aerial view of Nairobi CBD.
Source: Nairobi the 15th most expensive city to live in Africa and 95th in the world - SonkoNews

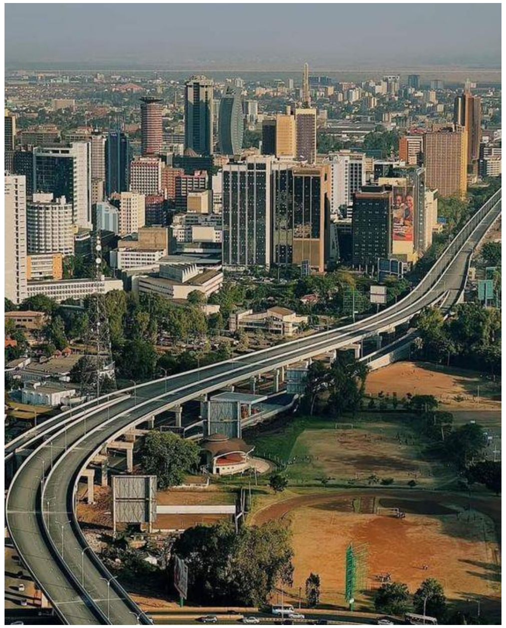


Figure 123 Part aerial view of Nairobi CBD.
Source: https://www.pinterest.com/pin/400679698110884159/

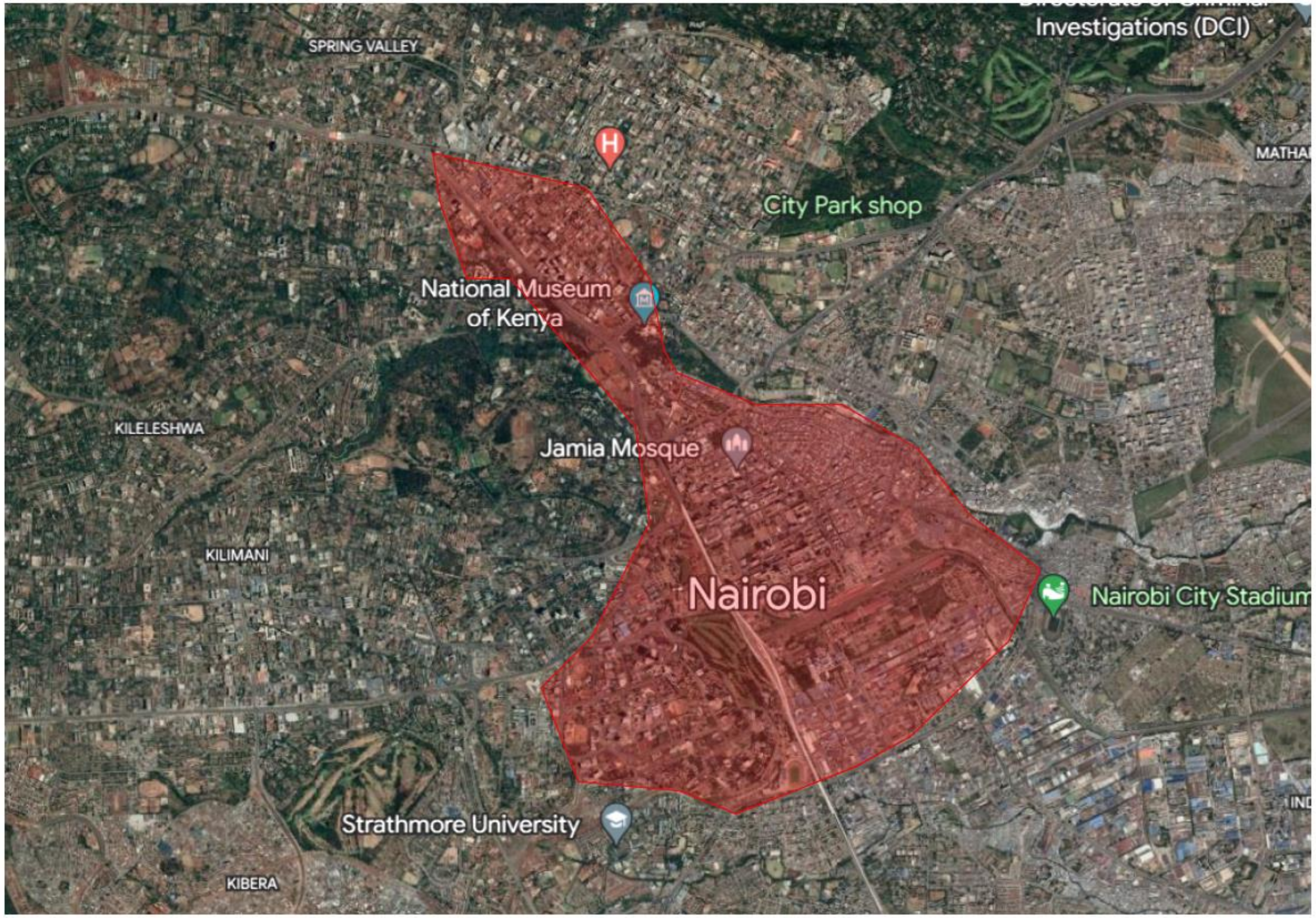


Figure 124 Area of Study. This includes the CBD and its neighbours that include Westlands and Upper Hill

Source: Google Earth, Author modified, 2023

Figure 125 Image showing part aerial view of Nairobi Upper Hill.

Source: Kpq37nD.jpeg (1357×681) (imgur.com)

Figure 126 Image is showing part view of Nairobi Westlands Area.
Source: maxresdefault.jpg (1280×720) (ytimg.com)

The area of study is the Nairobi Central Business and its neighbourhood including Westlands and Upper Hill. There has been a significant urban development project, in the expansion of Nairobi's CBD to Westlands and Upper Hill aiming to bring the city's central business district to these two fast-expanding commercial and residential areas.

To connect Westlands and Upper Hill to the current CBD, the extension project requires building new roads, bridges, and other transportation facilities. New commercial constructions like shopping centres, office buildings, and hotels are a positive addition as a result of the expansion.

Both Westlands and Upper Hill are significant economic centres, home to numerous multinational organizations and businesses. They are also home to several large hospitals, hotels, and financial organizations. This expansion of the CBD to Westlands and Upper Hill draws more investors and firms to these areas, producing more employment possibilities for the local populace. More building typologies have skyrocketed in these areas, offering new commercial opportunities.

4.2 Nairobi Climate Analysis (Wilson Airport Meteorological Station)

The initial stage in bioclimatic design is the analysis of climatic data. This strategy can be more accurate than ever thanks to computer-assisted techniques. A design strategy utilizing a building's bioclimatic chart was suggested by Givoni and Milne.

4.2.1 \Temperature Range

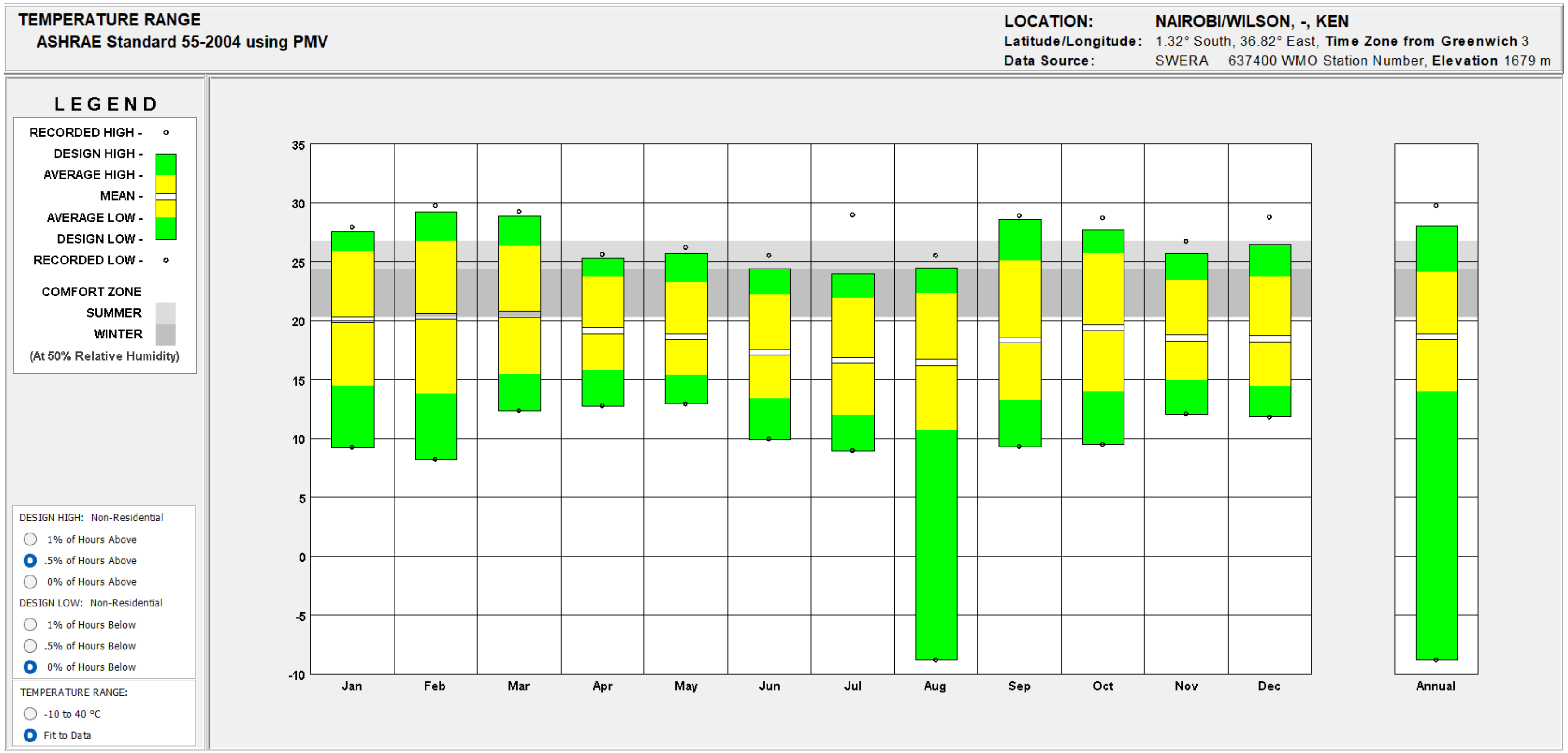


Figure 127 Image showing the Temperature Range graph for Nairobi.

Source: Author modified, 2023

It is possible to use local hourly meteorological information to analyse specific details for bioclimatic design thanks to simulation-based computers and energy design tools. Nairobi’s climate and weather patterns must be understood to design sustainable buildings. Climate consultant software and climate data from Wilson Airport Meteorological Department were used to generate charts and graphs for analysing Nairobi’s climate. Figure 127 shows the graph of the Temperature Range for Nairobi. The temperature change throughout the year must be carefully taken into account while designing buildings in Nairobi, Kenya. Nairobi has a subtropical highland climate, with year-round temperatures between 10°C and 28°C (50°F and 82°F).

To design pleasant and energy-efficient buildings, architects and engineers must take the following factors into account:

Building Orientation: A building's orientation plays a key role in temperature control.

The building is to be sited to maximize exposure to indirect sunlight while utilizing natural ventilation and daylighting. This will lessen the need for air conditioning by keeping the interior spaces cooler during the day. Building Envelope: is best used in the reduction of heat intake during the day and heat loss at night by designing the building envelope, which includes the walls, roof, and windows. Low-emissivity glass, shading equipment, and high-performance insulation can all aid in reducing heat gain and preserving comfortable interior temperatures.

Thermal Mass: Using thermal mass can assist in controlling indoor temperatures because it can absorb heat during the day and release it at night. Materials like concrete, brick, and stone can help keep interior spaces cooler during the day and warmer at night.

Mechanical Systems: The mechanical systems, like air conditioning and ventilation, are sized appropriately for the building and built to be energy-efficient. By doing this, it will be possible to lower energy expenses and consumption while keeping a cosy indoor climate.

Renewable Energy: Utilizing renewable energy resources, such as solar panels, can assist in counterbalance energy use and lessen a building's environmental impact.

In conclusion, temperature ranges throughout the year must be put into consideration while planning and designing buildings in Nairobi. To design buildings that offer thermal comfort, are energy-efficient, and are sustainable, architects and engineers must consider factors including building orientation, building envelope, thermal mass, natural ventilation systems, and renewable energy sources.

4.2.2 Monthly Diurnal Averages

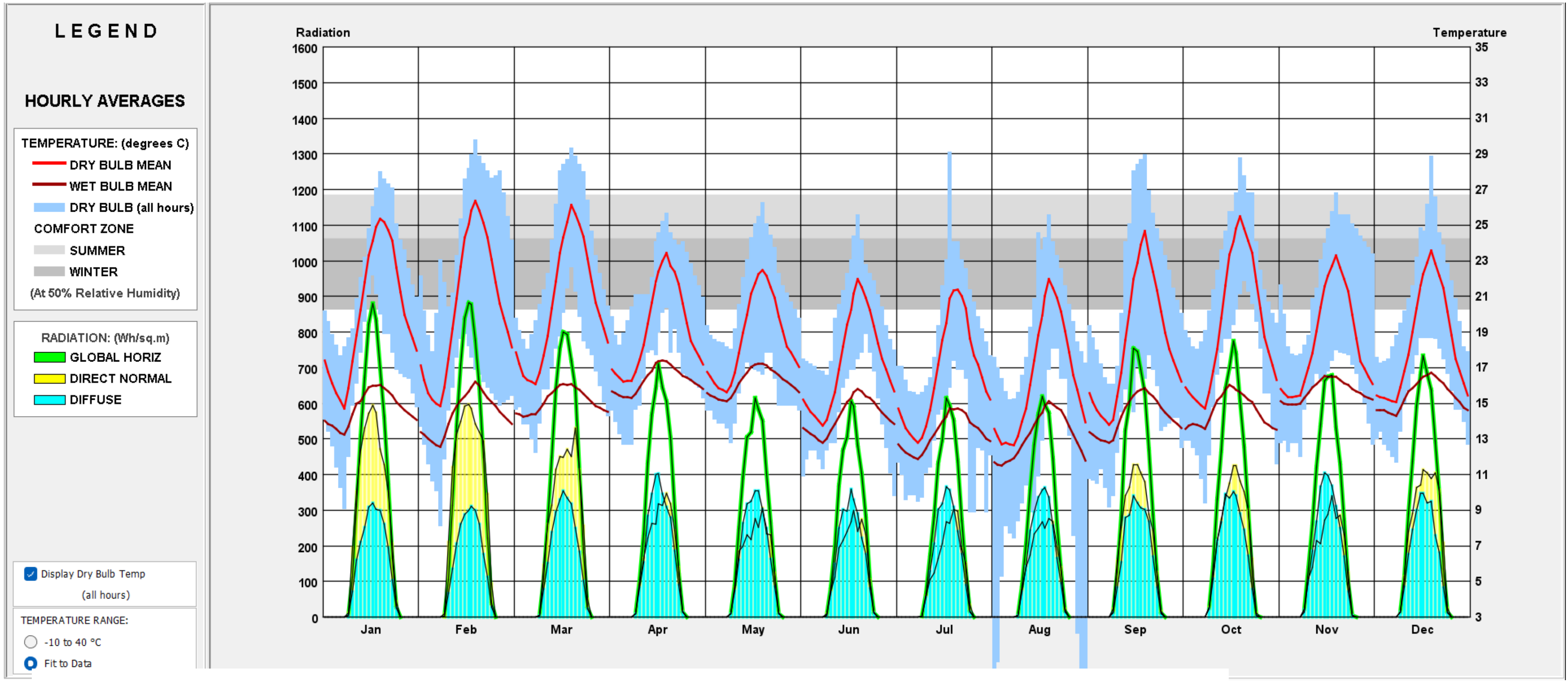


Figure 128 Image showing the Monthly Diurnal Averages graph for Nairobi.

Source: Author modified, 2023

Designing passively can assist maintain internal temperatures and lessen the need for mechanical cooling and heating by using techniques like natural ventilation, shade, and thermal mass. While shade measures should be employed to minimize overheating during the warmer portions of the day, the design should allow for natural airflow during the cooler hours of the day and night. Figure 128 shows the graph of Monthly Diurnal Averages for Nairobi.

Insulation: By minimizing heat transmission between a building's interior and outside, insulation can assist control internal temperatures. The insulation should be created with consideration for the unique demands of every month, taking into account the differences in temperature between day and night.

Glazing: The glazing must be designed to stop heating up during the day and loss during the night. Double-glazed windows help to prevent heat loss at night while low-emissivity glass can aid to reduce heat gain during the day.

In conclusion, the monthly diurnal average must be carefully taken into account while planning buildings in Nairobi. To control indoor temperatures and lower energy usage while maintaining a comfortable indoor environment, a variety of passive design techniques, insulation, glazing, mechanical systems, and renewable energy sources can be used.

4.2.3 Radiation Range

The radiation range, which refers to the quantity of solar radiation that the building is exposed to year-round, should be carefully taken into consideration when designing buildings in Nairobi, which has a tropical climate. Nairobi receives a lot of solar radiation all year round because of its proximity to the equator. Figure 129 shows the radiation graph for Nairobi’s climate.

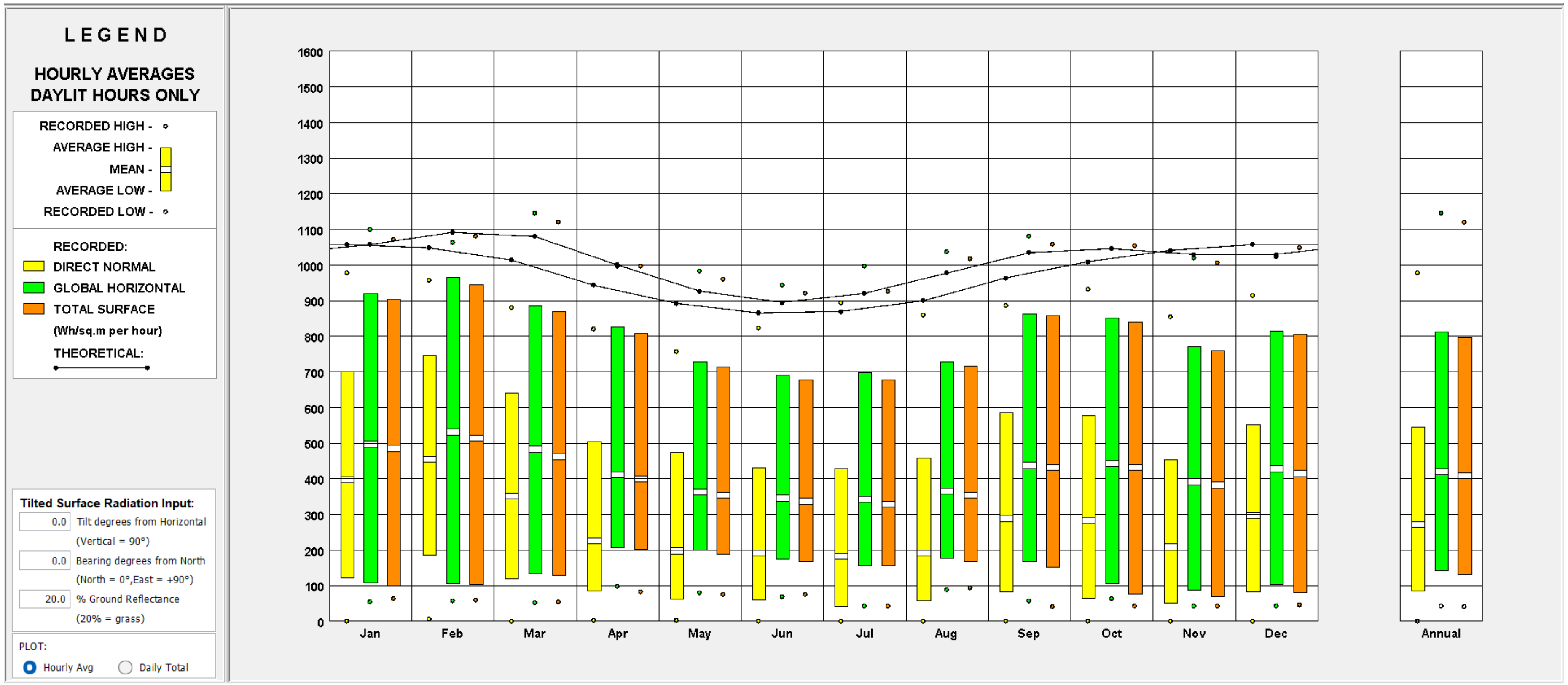


Figure 129 image showing Radiation Range graph.

Source: Author modified, 2023

The following radiation range-related issues must be taken into account by architects and engineers in order to develop comfortable, energy-efficient buildings:

Orientation: To control solar radiation, the building's orientation is crucial. A building must be situated to enhance exposure to indirect sunlight while utilizing natural shade and daylight. This will lessen the need for air conditioning by keeping the interior spaces cooler during the day.

Sun shading: Eaves, overhangs, and louvers are examples of shading structures that may help reduce glare and solar heat gain while still allowing for daylight to enter the building. To give shade during the hottest parts of the year and more direct sunlight during the cooler ones, the design should be improved.

Glazing: The glazing should be made to prevent heat loss at night and heat gain during the day. While enabling natural light to enter the building, high-performance glass with low solar heat gain coefficients can help to minimize solar radiation.

Insulation: By minimizing heat transmission between a building's interior and outside, insulation can assist control internal temperatures. Each season's unique requirements should be taken into consideration while designing the insulation, along with the solar radiation range.

Passive design: designing passively can assist maintain internal temperatures and lessen the need for mechanical cooling and heating by using techniques like natural ventilation, shade, and thermal mass.

Renewable energy: Solar panels, for example, can assist offset energy use and lessen the environmental effect of buildings.

In summary, the radiation range must be carefully taken into account when developing buildings in Nairobi. To control indoor temperatures and lower energy usage while maintaining a comfortable indoor environment, a variety of strategies can be used, including orientation, shading, glass, insulation, passive design, and renewable energy.

4.2.4 Illumination Range

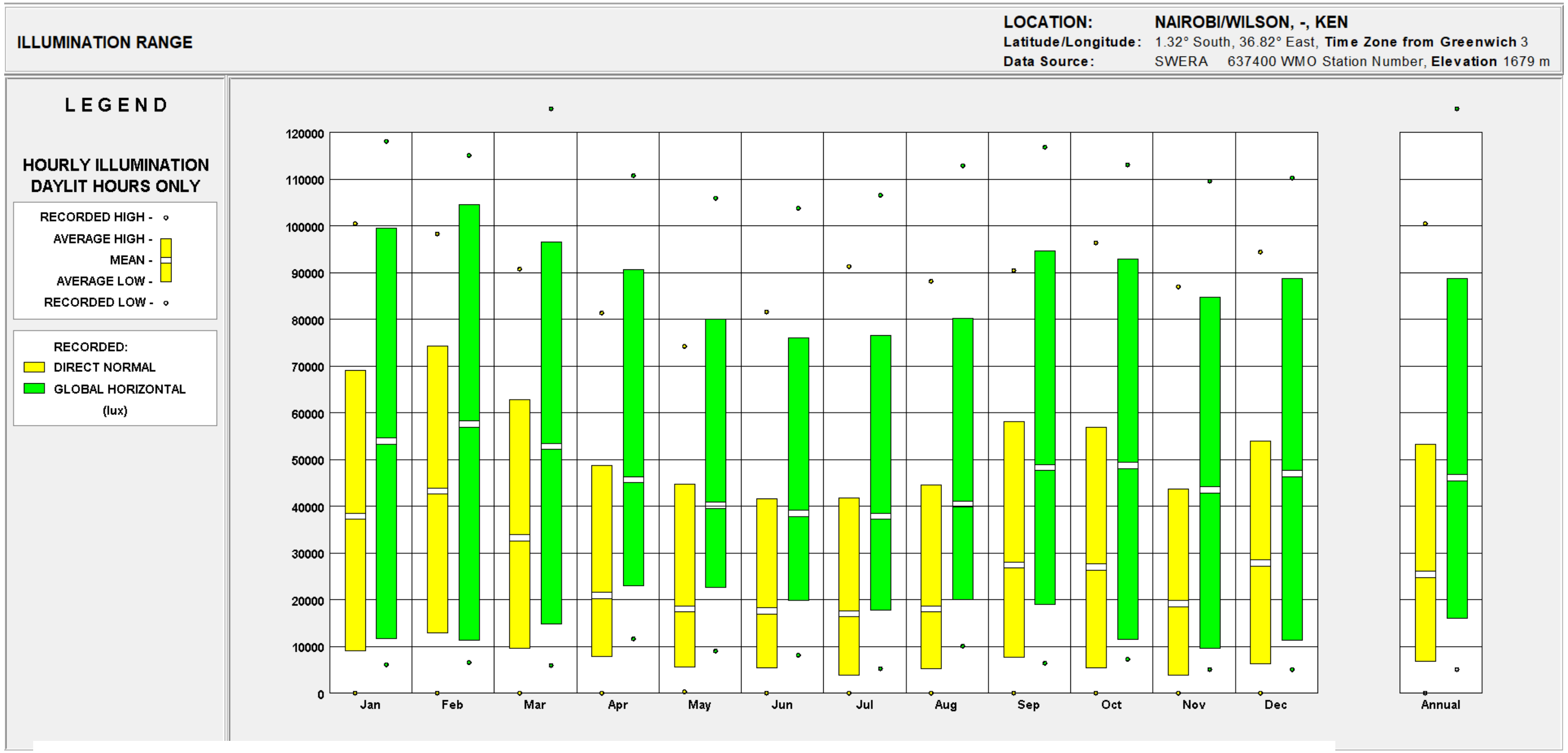


Figure 130 Image showing Illumination Range graph.

Source: Author, modified 2023

The general rule is that energy efficiency and occupant comfort will both increase in buildings that are built to optimize natural light. Strategic window placement and the use of daylight-permeable materials can accomplish this. To maintain a suitable level of illumination, however, extra artificial lighting may be required in locations where the illumination range is extremely low, such as during the rainy season. Figure 130 shows the graph of the illumination Range for Nairobi.

4.2.5 Sky Cover Range

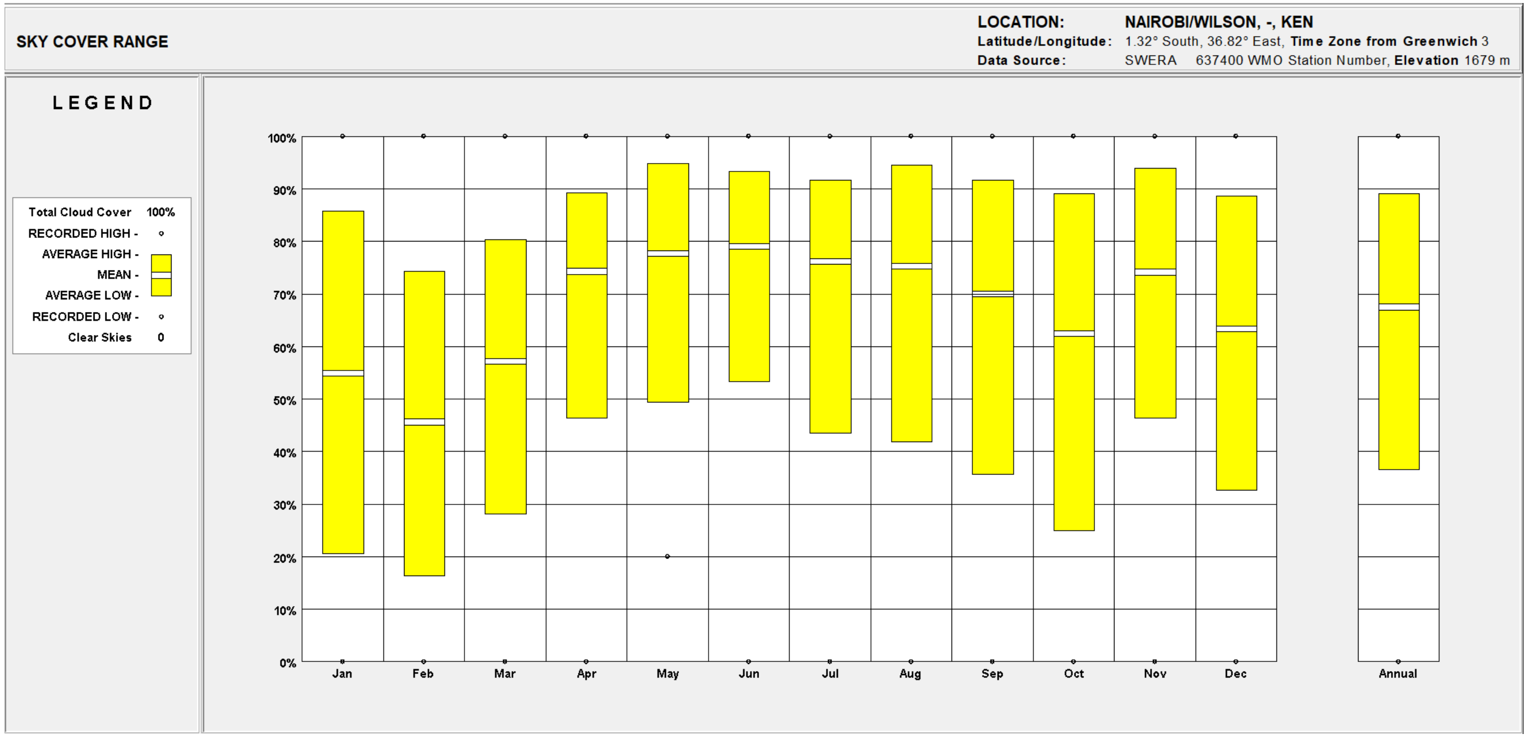


Figure 131 Image showing Sky Cover Range graph.

Source: Author modified, 2023

Few months in Nairobi have a clear sky, only the month of February with less than 20% cloud cover of the sky. The annual mean sky cover range is 68%. This is important in designing energy-efficient architecture. This investigation helps to size the optimal window sizes and placement, and appropriate shading and light-diffusion strategies. From the chart, Solar PV Systems would be effective from the rooftops of the buildings.

4.2.6 Sun Shading Chart

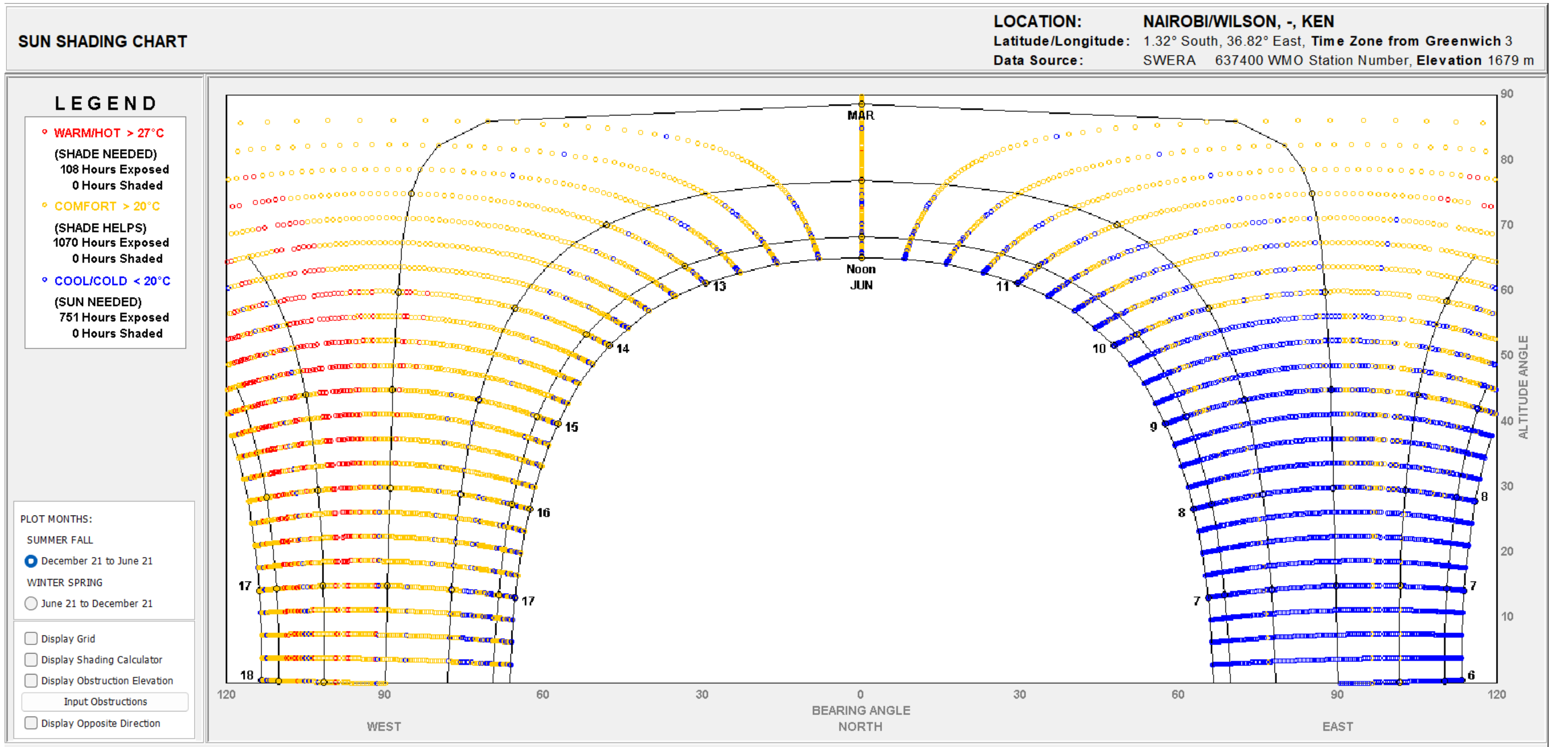


Figure 132 Image showing sun shading chart.

Source: Auhor modified, 2023

Sun shading charts are also called sun path diagrams showing the position of the sun at several periods of the day and year. They help in designing buildings and outdoor spaces that maximize natural light and minimize unwanted solar heat gain. From the chart above buildings in Nairobi are exposed to the sun for more than 108 hours during the hottest months of the year above 27 degrees Celsius. Above 20 degrees Celsius, buildings are exposed for 1070 hours, which would require sun shading. In conclusion, buildings in Nairobi would require sun shading for unwanted solar heat gain.

4.2.7 **Wind Velocity**

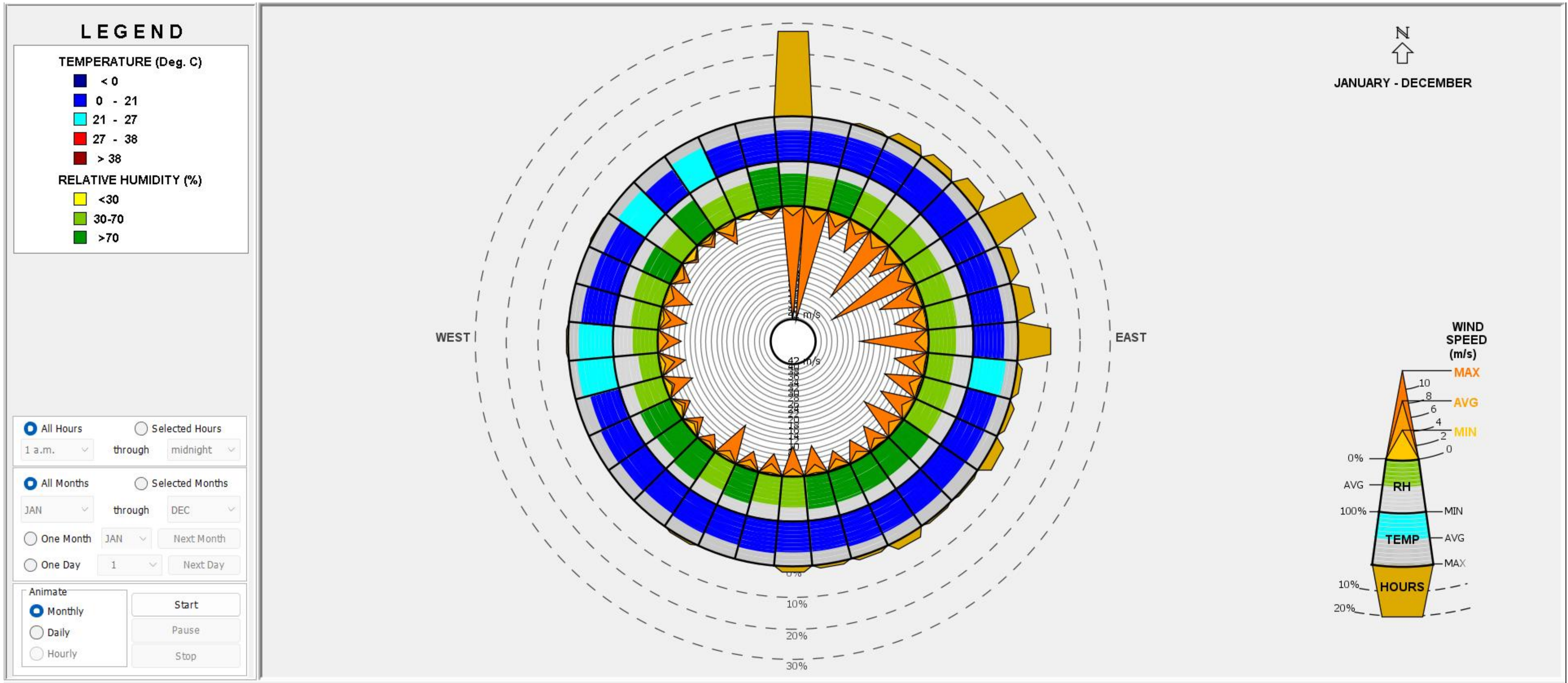


Figure 133 Image showing wind velocities and wind Rose.

Source: Auhor modified, 2023

Nairobi has moderate to strong winds on average throughout the year, with the heaviest gusts during the dry season. The average wind speed in Nairobi varies between 10 and 15 kilometers per hour (km/h) during the wet season and between 15 and 20 km/h during the dry season as shown in the Wind Rose. Figure 133 shows wind velocities and wind Rose chart for Nairobi

It's crucial to keep in mind that wind speeds vary significantly based on the time of day, the precise location inside Nairobi, and the current weather. For instance, wind speeds might be substantially higher during thunderstorms or other extreme weather conditions. When considering wind velocity for sustainable building design, keep the following things in mind:

Wind direction: When planning buildings to benefit from natural ventilation, it is essential designers understand the direction of the prevalent wind. During the dry season, the main direction of the wind in Nairobi is from the southeast, and during the wet season, it is from the east. Buildings should be designed to take advantage of these prevailing winds so that airflow is possible and mechanical cooling is not necessary. Nairobi has moderate to strong winds throughout the year, as was already noted. These speeds can be employed to operate wind catchers, which pull air in from the outside which is cooler, and push heated air out of a building, as well as other natural ventilation systems.

Design of the building: A building's design can have an impact on the direction of the wind. Narrow floor plates and high buildings can generate wind tunnels that boost wind speeds and enhance natural ventilation. Additionally, adding elements like balconies, courtyards, or atriums can aid in creating microclimates that improve passive cooling and natural ventilation.

4.2.8 **Psychrometric Chart**

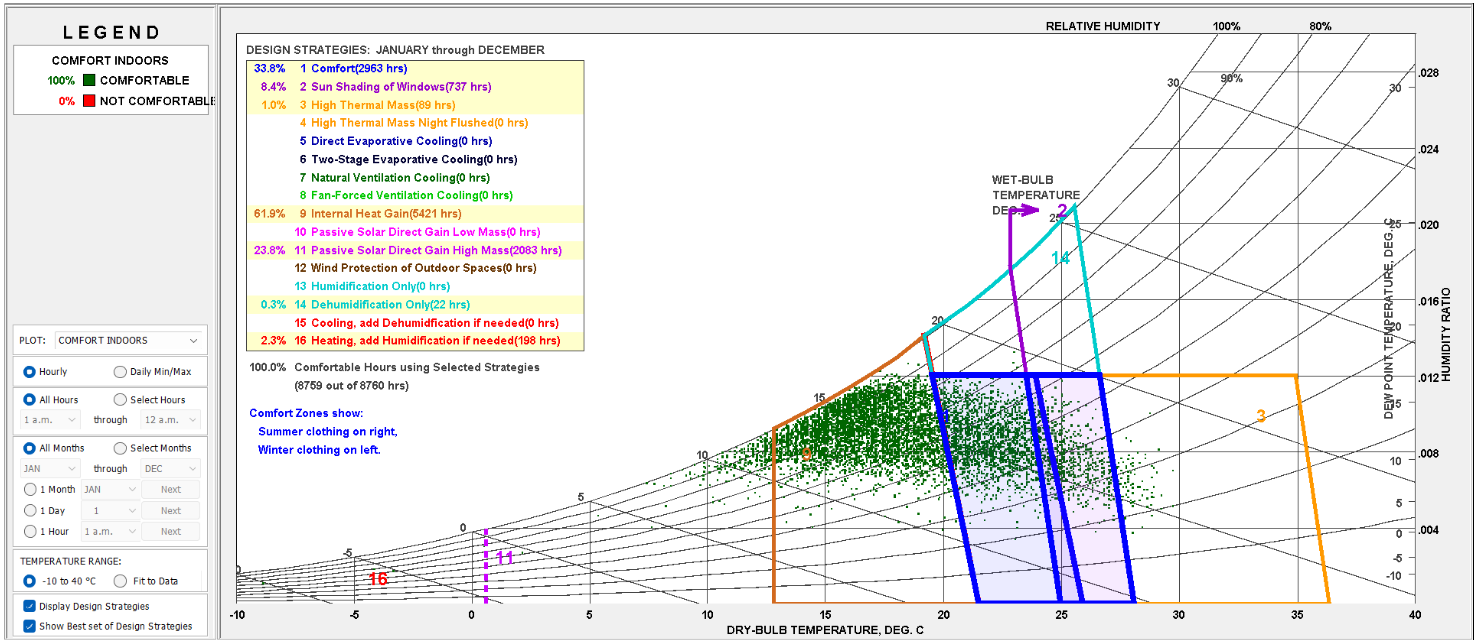


Figure 134 Psychrometric Chart – Eliminating Design Strategies.
Source: Auhor modified, 2023

A psychrometric chart shows the thermodynamic properties of air graphically. It is a crucial tool when designing buildings since it aids in the analysis of the moisture content and cooling needs for inside spaces. Figure 134 and figure 135 show a Psychrometric chart – Eliminating design strategies and with most important design strategies respectively for Nairobi. Climatic factors can be plotted on a psychrometric chart and then analysed to help us design buildings that offer their occupants thermal comfort. For instance, we can use the psychrometric chart to calculate the amount of sensible and latent heat that needs to be removed from the air to determine the air conditioning requirements for indoor spaces.

For 100% comfort inside buildings in Nairobi, the following design strategies must be employed; Sun shading for windows; Internal heat gain, high thermal mass High mass solar passive direct gain and dehumidification.

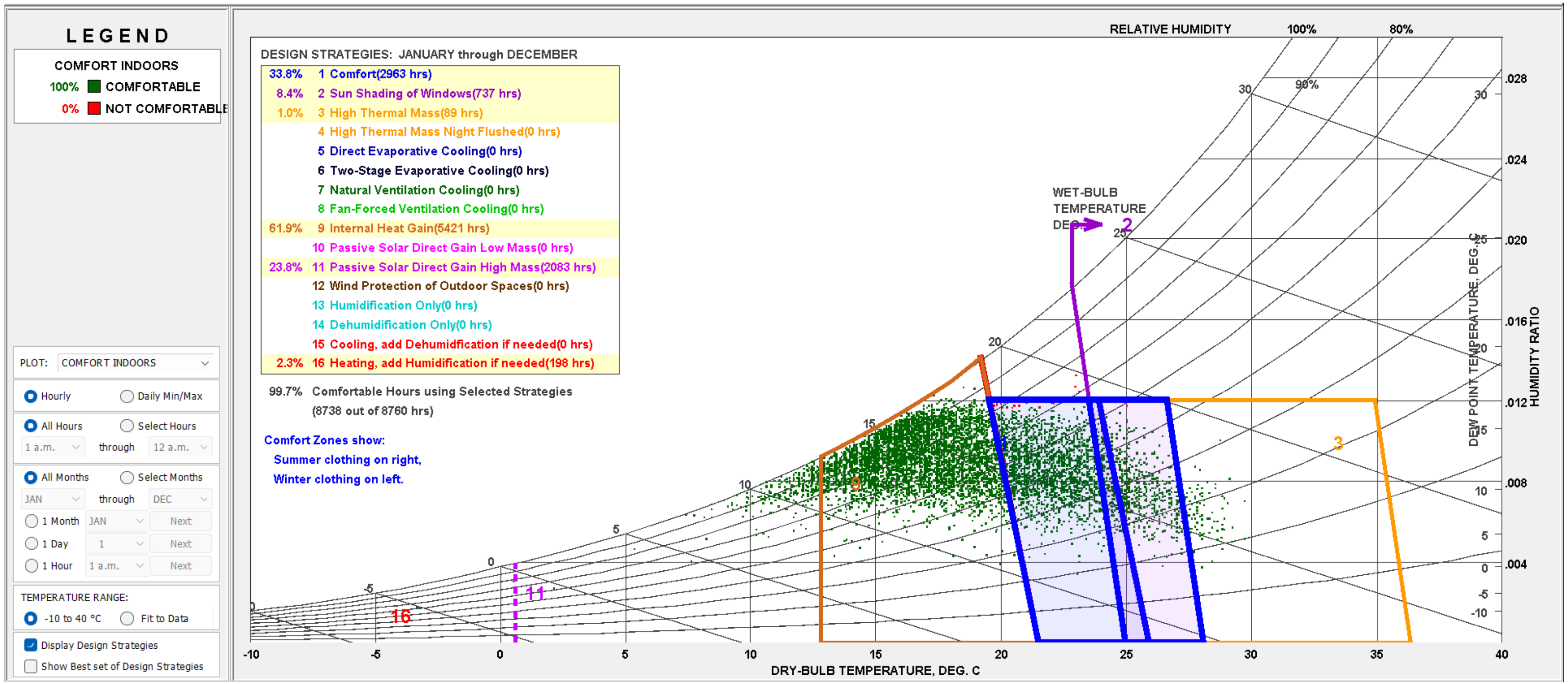


Fig. 135 Psychrometric Chart with most important design strategies only.

Source: Auhor modified, 2023

4.3 Case Study Analysis with Occupancy Levels and energy consumption of Buildings

When assessing a building's efficiency, it's important to take into account both occupancy levels and energy consumption. To compare and analyse the two, the following needed to be considered;

i. Benchmarking: Benchmarking, which entails contrasting the energy performance of comparable buildings, is one method of comparing occupancy and energy usage. This can aid in locating anomalies and areas for development. For instance, if the energy consumption levels of two buildings with comparable occupancy differ, it can be a sign that one of the buildings is less energy-efficient.

ii. Patterns of occupancy: Examining patterns of occupancy can reveal when and how much energy is being used in a building. For instance, a building that is frequently occupied during the daytime may require more energy at certain times due to increased lighting and HVAC demand.

iii. Implementing energy management systems; can aid in real-time monitoring and analysis of energy consumption. This can assist pinpoint locations where energy is being wasted and offer suggestions for lowering energy use.

iv. Behaviour modification: Promoting energy-saving habits among building inhabitants can help cut down on energy use. For instance, conserving energy can be achieved by turning off lights and devices when not in use, utilizing natural lighting wherever available, and modifying thermostat settings.

v. Design of the building: A building's design can have a big impact on how occupied it is and how much energy it uses. For instance, a building that is glass-cladded may use more energy in heating or cooling during the hot and cold seasons respectively, while a bio-climatically designed building might be comfortable in extreme weather conditions.

In conclusion, occupancy levels and energy use are intertwined and both must be taken into account when evaluating a building's efficiency. It is feasible to maximize energy efficiency and lower energy consumption in buildings via benchmarking, examining occupancy patterns, establishing energy management systems, encouraging behaviour change, and taking building design into account.

Following the collection of data from 30 buildings in Nairobi, empirical evidence is presented in this chapter. The sample included structures that were both privately and publicly owned and operated. The purpose of this chapter is to examine the occupancy and energy efficiency of both glass-clad structures and buildings with bioclimatic designs in Nairobi.

The data collection process was done using a questionnaire (see appendix), which was directed to building managers and or caretakers. A sample of 40 buildings was taken 20 for glass-cladded and 20 bio-climatically designed buildings. The buildings consisted of office blocks which are more than six stories. Among the 40 questionnaires issued, only 30 were well-filled showing a response of 63%. The fundamental issue underlying this is the lack of knowledge on the energy use of buildings and individual building components. The measure of variables collected are building area, percentage of occupancy, rent per m2, no. of people per m2, occupancy tenancy period, and mean energy use per year. Table 5 shows the Data input matrix.

BUILDING	Building Area	Percentage of	Rent per M2 per ear	No. of People per l2	Occupancy enancy period	Mean annual nergy use WH/Yr
	X1	X2	X3	X4	X5	E
Afya Centre	27,400	60	9,032	2	2	462,538
AM Bank House	19,700	60	14,839	1	6	507,692
Coop Bank	21,800	100	-	1	5	1,384,615
I&M Building	16,525	70	11,613	1	6	419,184
Lonhro House	22,765		14,968	1	6	696,000
Prism Building	26,565	90	14,194	1	5	415,385
View Park Tower	18,620	75	13,290	1	6	553,846
The Address	20,439	75	16,129	1	6	417,390
One Africa Place	12,820	65	18,064	-	6	-
Delta Chambers	12,698	70	18,064	1	5	360,000

BUILDING	Building Area	Percentage of ccupancy	Rent per M2 per ear	No. of People per l2	Occupancy enancy period	Mean annual nergy use kWH/Yr
	X1	X2	X3	X4	X5	E
Britam Tower	31,500	100	12,903	1	6	-
Chester House	14,600	90	16,775	1	1	260,000
Electricity House	14,255	75	17,419	1	6	692,308
ICEA Building	18,200	70	11,613	1	6	1,304,348
IPS Building	3,065	98	10,323	1	5	629,687
Kencom House	14,800	100			1	276,170
Kenindia House	16,500	100	10,323	1	4	507,692
KICC Building	35,190	100	-	1	4	-
NHC Building		70	14,194	1	6	-
Nyayo House	26,690	100	-	1	-	1,038,462
ST. Georges	-	75	16,775	2	6	-
Old Treasury	9,035	100	-		-	-
Maendeleo House	7,050	100	11,613	1	6	10,7870
Nation Centre	14,800	75	14,940	1	5	432,000
Norwich Union	9,600	100	15,490		6	208,700

Table 5 Data input matrix.

Source: Author Field Survey, 2023

4.3.1 Effects of Building Area on Mean Annual Energy Use

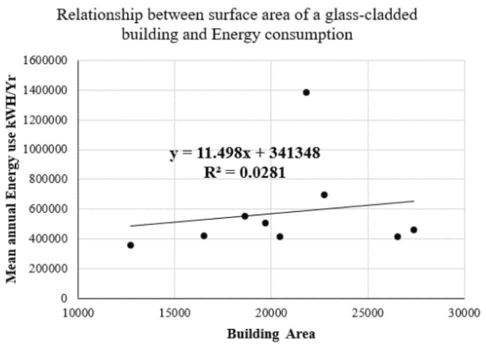


Figure 136 Image showing graph of mean annual energy use against building area for glass cladded buildings.
Source: Author, 2023

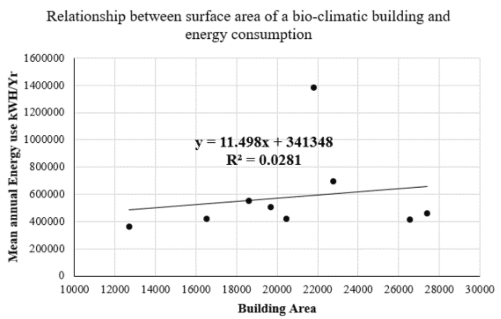


Figure 137 Image showing graph of mean annual energy use against building area for bioclimatic buildings.
Source: Author, 2023

Building design, orientation, insulation, HVAC system, and occupancy patterns are just a few of the variables that affect how much energy a building uses on a yearly average. However, energy use tends to increase along with building area. Figure 136 and Figure 137 show the graph of mean annual energy use against building area of glass cladded buildings and mean annual energy use against the building area of bio-climatically designed buildings respectively.

This is because maintaining a suitable indoor atmosphere typically requires more heating, cooling, and lighting in larger structures. Additionally, larger buildings frequently house more occupants, which may result in higher energy consumption from equipment like electronics and appliances.

It's crucial to remember that just expanding a building's footprint does not automatically result in higher energy use. Even with a bigger space, an energy-efficient structure with sufficient insulation, an effective HVAC system, and the utilization of natural lighting can significantly cut energy use.

Even though a larger building may use more energy overall, if it uses less energy per unit of area than a smaller building, it is regarded as being more energy-efficient. The impact of building area on mean yearly energy use is complicated and influenced by a number of variables. Larger building areas may result in an increase in energy consumption, but this increase can be minimized by designing and managing buildings with energy efficiency in mind.

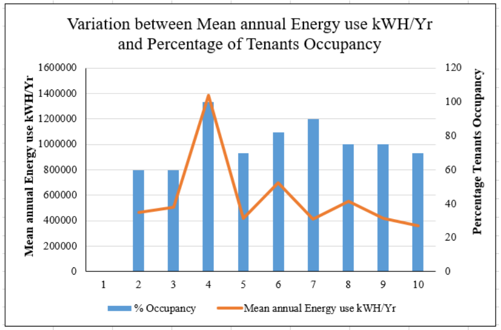


Figure 138 Image showing graph of mean annual energy use against occupancy for glass cladded buildings.
Source: Author, 2023

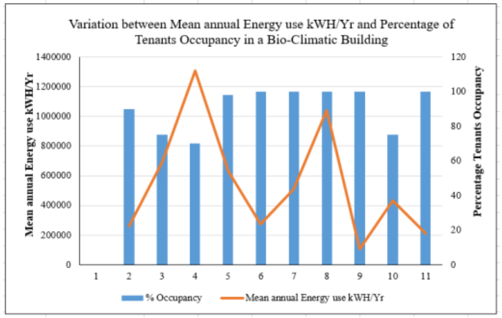


Figure 139 Image showing graph of mean annual energy use against occupancy for bioclimatic buildings.
Source: Author, 2023

4.3.2 Effects of Occupancy on Mean Annual Energy Use

Its typical annual energy usage can be significantly impacted by occupancy trends. This is because the energy use of most building systems, including heating and cooling, lighting, and devices, is closely associated with the number of people using the space. Figure 138 and Figure 139 show the graph of mean annual energy use against occupancy of glass cladded buildings and mean annual energy use against occupancy of bio-climatically designed buildings respectively.

Energy demand tends to rise at times of high occupancy, such as during business hours or events, because more lighting, HVAC, and other equipment are required to accommodate the extra occupants. Similarly, to this, energy use tends to drop during times of low occupancy levels, such as overnight or on the weekends, as fewer resources are needed to maintain a comfortable indoor environment.

A building's occupants' behaviour and activities, in addition to their number, might affect energy usage. For instance, inappropriate use of energy-intensive equipment or leaving lights on in unoccupied spaces can raise energy consumption. On the other hand, residents who alter their behaviour to reduce energy consumption, such as using natural ventilation rather than air conditioning, or turning off lights and equipment when not in use, can help to lower energy use.

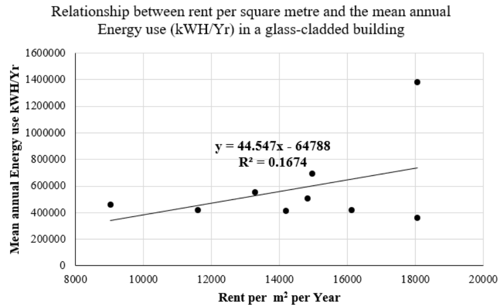


Figure 141 Image showing graph of mean annual energy use against rent per m2 per year for glass cladded buildings.

Source: Author, 2023

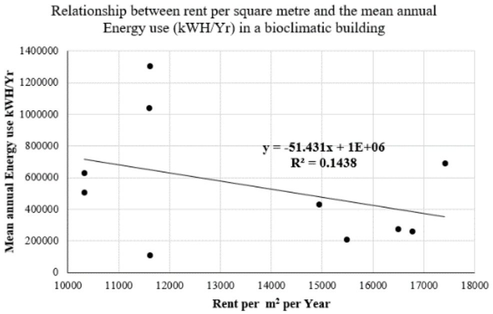


Figure 140 Image showing graph of mean annual energy use against rent per m2 per year for bioclimatic buildings.

Source: Author, 2023

4.3.3 Effects on Rent per square metre against Mean Annual Energy Use

Buildings that use less energy often have reduced operating expenses, which can increase their appeal to renters and possibly increase their rent per square meter. When compared to lesser efficient buildings, prices rise for buildings that are energy-efficient which can exceed six percent in the US, according to data collected by Lawrence Berkeley National Laboratory. This suggests that tenants are prepared to pay more for energy-efficient structures, possibly because they are aware of the long-term financial benefits of lower electricity costs. Figure 140 and Figure 141 show the graph of mean annual energy use against rent per m2 of glass cladded buildings and mean annual energy use against rent per m2 of bio-climatically designed buildings respectively.

According to a different study from the University of California, occupants of energy-efficient buildings are happier with their indoor surroundings, which can boost productivity and tenant retention rates. This implies that reducing tenant turnover and lowering vacancy rates are two indirect advantages of energy efficiency for landlords.

It's crucial to remember that the connection between rent per square meter and energy efficiency is complicated and can change based on the region, the state of the market, and tenant preferences.

Overall, the comparison of rent per square meter and energy efficiency might offer insightful information about the possible financial rewards of making energy efficiency investments. Energy efficiency can help to lower operating costs and increase tenant happiness, which can ultimately result in greater rent and better financial performance for landlords, even if the link may be complex and context-dependent.

4.4 Energy Efficiency by Simulation of Buildings

Building energy performance is predicted using computer models in a process known as energy efficiency simulation. This entails modelling the building's numerous energy systems and elements such as heating, cooling, lighting, ventilation, and the building envelope under various operating scenarios.

Energy efficiency simulation is used to find ways to cut back on energy use while enhancing building performance. Designers and engineers can assess the efficacy of various energy efficiencies techniques, such as the use of high-performance insulation, efficient lighting and HVAC systems, and renewable energy sources, by modelling various situations and comparing the outcomes.

The simulation program simulates the thermal behaviour of a building and its parts employing mathematical models that take into consideration factors including heat transport, the flow of air, and solar radiation. To make a precise projection of the building's energy use, the software also takes into account the occupancy patterns, internal heat gains, and weather conditions. Throughout the whole building design process, from the initial concept design to the post-occupancy evaluation, energy efficiency simulation can be applied. It helps architects, engineers, and other design and operation personnel in making decisions that maximize energy efficiency and cut down on energy expenses.

4.5 Applied Methodology for Energy Simulation

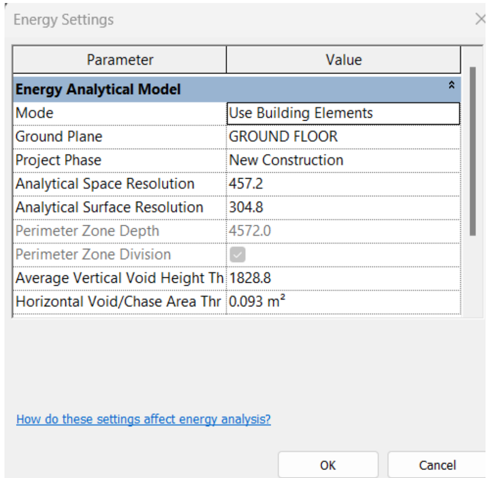


Figure 142 Image showing Energy management dialogue box in Revit.

Source: Author

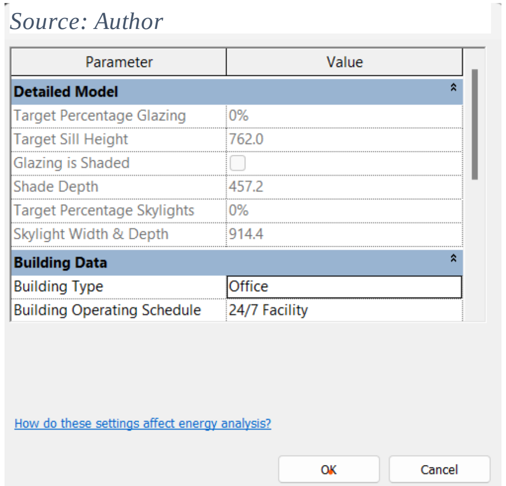


Figure 143 Image showing advanced Energy management dialogue box in Revit.

Source: Author

Autodesk Revit is commonly utilized for energy analysis using the Revit software. The office buildings being analysed are located in Nairobi CBD and Westlands. Building a three-dimensional model of the buildings allows for analysis, which is then carried out on Autodesk insight. Figure 142 – 145 shows the images of the dialogue box settings process. The Autodesk Revit programs in the cloud energy simulation assistance, which is run with Autodesk's Green Building Studio, facilitate sustainable design and speed up the procedure of energy evaluation for building projects. This robust piece of software focuses on the organization and recording of the input data. The Autodesk-developed features and tools which make up Revit Architectural Design, which was made exclusively for architects as well as other building professionals, enable building information modelling (BIM) workflows.

The three buildings are simulated by Autodesk using the following steps:

1. The drawing of the specified form is examined after gathering all the essential information.
2. By employing the Autodesk Revit program, a 3-D model of the structure is created based on the collected drawings.
3. Based on data regarding wall, roof, and window components in addition to energy setting types such as heating and cooling plug loads, efficiency, operation schedules, etc., the appropriate modifications are made.
4. The program has been set up with the geographic location of the building under examination with the Internet Mapping Service.

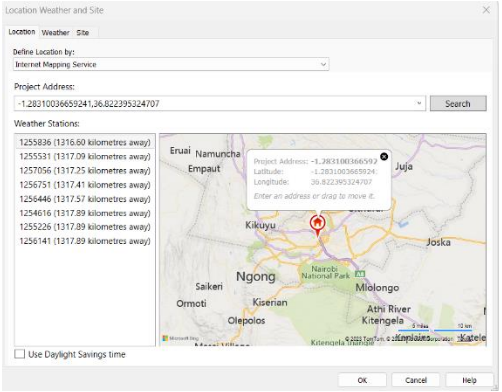


Figure 144 Image showing locating of the building using the Internet Mapping Service (IMS).

Source: Author, 2023

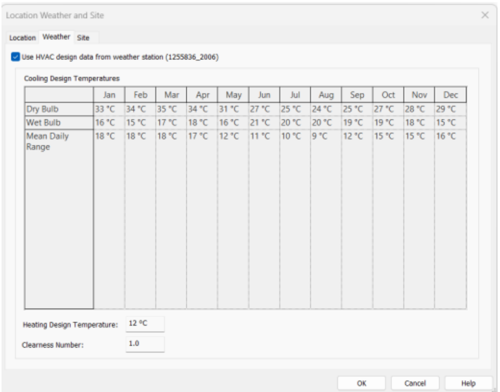


Figure 145 Image showing locating of the building using the IMS with the weather data from the nearest Meteorological station.

Source: Author, 2023

5. The evaluation panel in the Revit program automatically creates a building energy model.

6. Following the creation of the building's energy model for structural optimization, the Insight Autodesk plugin opens in a new window. Insight provides examples of the possible performance outcomes of various design situations.

7. Based on the variables set in the Autodesk insight program, we estimate the building's ultimate energy requirements and cost.

If thermal qualities are taken into account during the creation of the 3D model, we must choose that specific material from the available list of thermal properties. The energy model creation process is managed using the available energy settings It is used to implement the use of additional data supplied during model construction, such as material properties and heat space parameters. Energy settings are not required for the first energy optimization. There are certain default parameters for the energy setting used in the model's development.

The Advance Energy Setting is used to determine the factors that have an influence on the structure's energy use after doing an initial energy analysis. The program enables users to customize each material's Heat Resistivity and Thermal Transfer Coefficient values based on the types of materials used to build it. To create silhouettes for solar studies, demonstrations, and produced images, the building was located employing Revit's integrated Internet Mapping service capabilities after it was created. The geographical conditions were entered. It also helped in identifying meteorological data and a weather station of the building under investigation, which speeds up the study process even further.

Choosing a creative energy model effectively develops an energy analytical model when the fundamental and developed energy settings are complete. With the help of this feature, we may examine and verify the Energy analytical model before running the Energy simulation. One of the essential elements of efficient and successful energy optimization is the automated production of a building's energy model. This characteristic demonstrates that a unique model is not required for the building analysis. After developing the energy analytical model, we now optimize the building's energy use. To do this, select the energy optimization tool. Through the Auto Desk Insight plugin, we get access to the findings of the energy analysis.

4.5.1 Result

Three buildings were modelled using Autodesk Revit and analysed. These buildings are The Chambers in Westlands which is a glass-cladded building, the Nation Centre, characterized as a modern building and the ICEA building which is characterised as a bioclimatic building. The choice of the buildings was done on the availability of their documented information. We can get information about the three buildings' environmental performance and energy efficiency in Revit.

The length of the energy optimization procedure would depend on the kind and complexity of the construction. After creating the energy analytical model using Revit's energy optimization, we use Autodesk Insight to evaluate the building's performance. The Autodesk plugin will notify you when the energy analysis phase of the project is complete. Energy use intensity (EUI), or the yearly kWh/m2 consumption rate, is calculated. The energy usage intensity of a building is defined as the ratio of its annual total energy use to its total built-up area. The study report created by Autodesk Insight includes many design alternatives for controlling the building's energy consumption, including building the orientation, windows-to-wall ratio, window shading, roof and wall framework, plug load efficiency, and lighting efficiency. The report that has been generated tells us the building's yearly energy cost / per square meter of space as well as its Energy Use Intensity (EUI).

4.6 Case Study Analysis by Simulation

4.6.1 Case Study 01: Energy Efficiency Analysis – Delta Chambers, Westland's Nairobi

1 **Introduction**

Delta Chambers is ideally situated along Waiyaki Way in Westlands next to the famous Delta Corner and just minutes from Westlands and Nairobi's Central commercial sector, at the centre of what is gradually emerging as Westlands' main commercial sector.

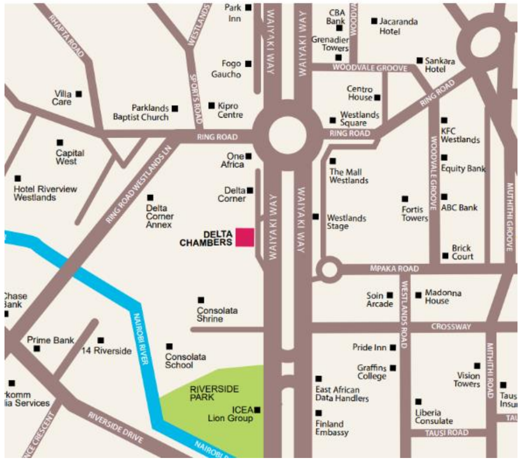


Figure 146 Location Map showing Delta Chambers. Source: Delta Chambers - Real Estate Market Research and Data Nigeria and Africa - ei - Estate Intel

Figure 147 Image of Delta Chambers, Nairobi. Source: Delta-Chambers-750x450.jpg (750×450) (towercost.co.ke)

Figure 148 map view of Delta Chambers being analysed.

Source: Author adopted from google maps, 2023

Figure 149 Ground Floor Plan.
Source: Delta Chambers - Real Estate Market Research and Data Nigeria and Africa - ei - Estate Intel

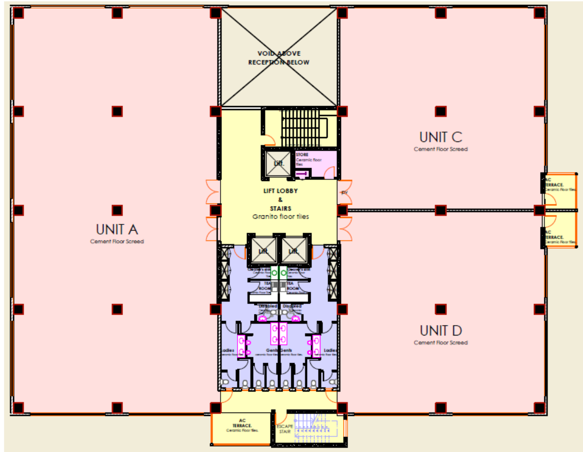


Figure 150 First Floor Plan.
Source: Delta Chambers - Real Estate Market Research and Data Nigeria and Africa - ei - Estate Intel

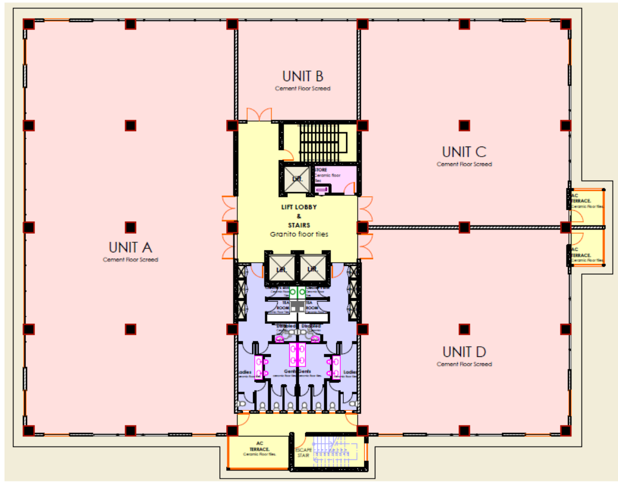


Figure 151 Typical Floor Plan.
Source: Delta Chambers - Real Estate Market Research and Data Nigeria and Africa - ei - Estate Intel

The project spans from the ground floor to the eighth floor, with a total lettable area of 135,000 square feet. The facility provides space for offices. The development is a cutting-edge commercial office building that was created by INNOVATIVE Planning and Design Consultants Architects and constructed by Kanaiya Builders Ltd. Parameters assessed for energy efficiency for the Delta Chambers building are highlighted below.

1. Site Selection: the building's orientation does not observe the East-West axis. All the four elevations are exposed to the sun.
2. Site Planning: their planning of the building does not help in the energy efficiency of the building. There are no buildings closer to Delta Chambers. The few plants are not helpful in changing the micro-climate.
3. The building form; the building's form is almost square creating more surface area exposed to the sun. This heats up the building very fast during the hot periods. This requires more energy to cool the building.
4. Building plan and appropriate space organization: all the internal working spaces are exposed to direct sunlight, and the staircase, wet areas, and other services should have been located on the East and West facades of this building.
5. Building Envelope: the building is glass cladded on all four elevations. It does not have any sun shading devices making it fully exposed to direct sunlight.
6. Choosing energy-efficient building materials: Most of the materials used apart from Aluminium and glazing have been locally sourced, they are durable and can be recycled.
7. Energy Efficient Landscape Designs: this has not been done effectively.
8. Use of Renewable Energy resources; this has not been utilised in this project.
9. Occupancy: the building's occupancy is at 70%. As a relatively new building compared to the rest, the occupancy level should be at 90-100%. Other factors however could be a reason for its occupancy rate.

2 Simulation Results

Figure 152 Image showing Benchmark Comparison for Delta Chambers Building.
Source: Author

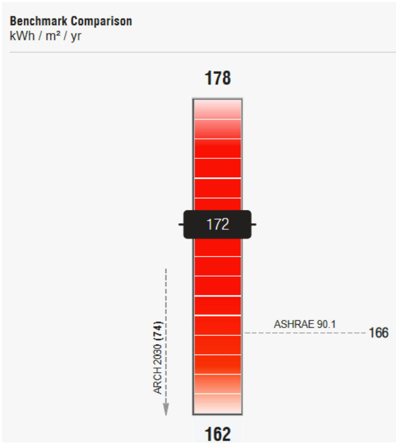


Figure 155 Image of Delta Chambers Building model.
Source: Author, 2023

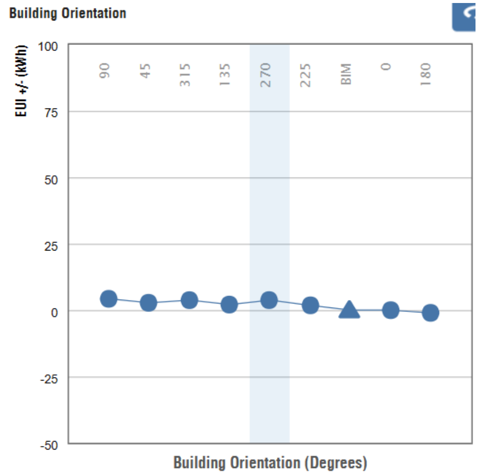


Figure 154 Image of graph showing building EUI against Orientation from the simulation of the Delta Chambers.
Source: Author, 2023

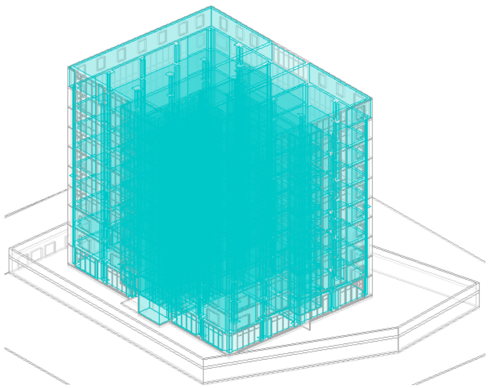


Figure 153 Image of generated analytical model of Delta Chambers Building.

Source; Author, 2023

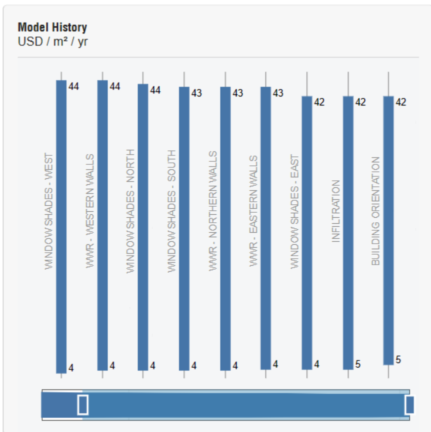


Figure 157 Image showing Model History for Delta Chambers Building.
Source; Author, 2023

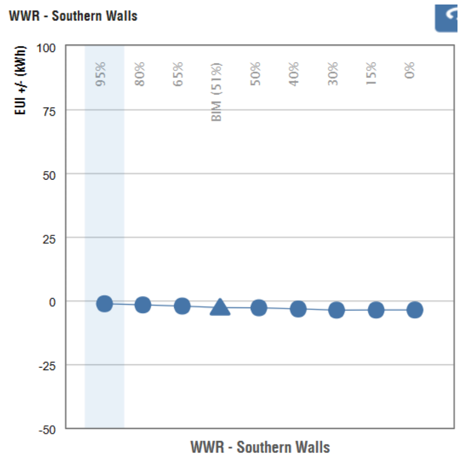


Figure 156 Image of graph showing building EUI against Orientation from the simulation of the Delta Chambers.
Source: Author, 2023

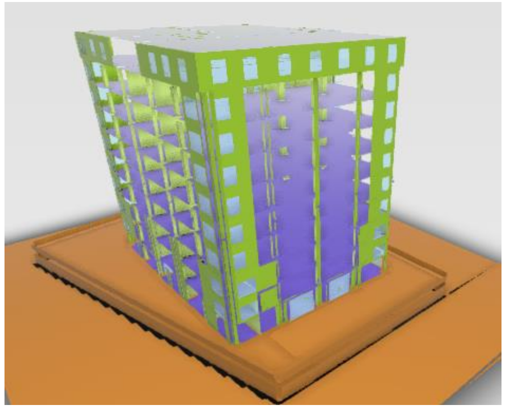


Figure 158 Image of optimized analytical model of Delta Chambers Building.

Source; Author, 2023

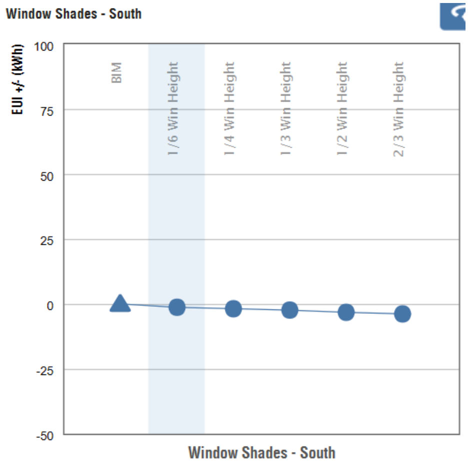


Figure 160 Image showing graph of EUI against Window Shades - South for Delta Chambers Building.
Source: Author, 2023

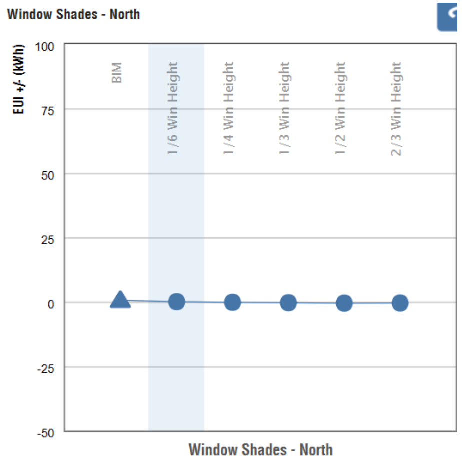


Figure 159 Image showing graph of EUI against Window Shades – North for Delta Chambers Building.
Source: Author, 2023

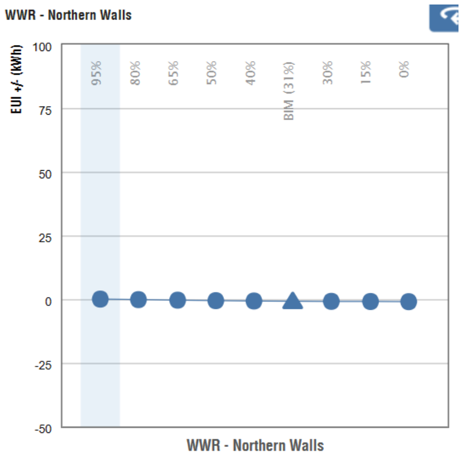


Figure 161 Image showing graph of EUI against WWR – Northern Walls for Delta Chambers Building.
Source: Author, 2023

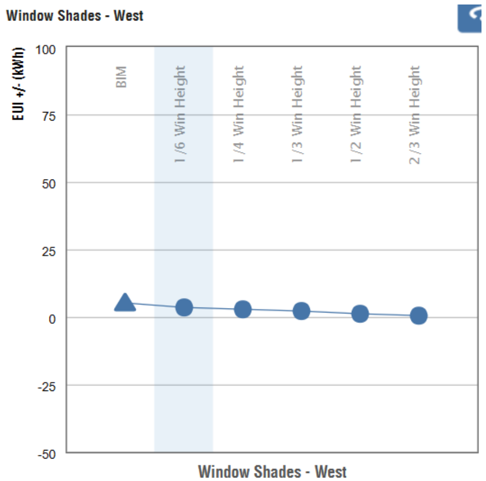


Figure 162 Image showing graph of EUI against Window Shades - West for Delta Chambers Building.
Source: Author, 2023

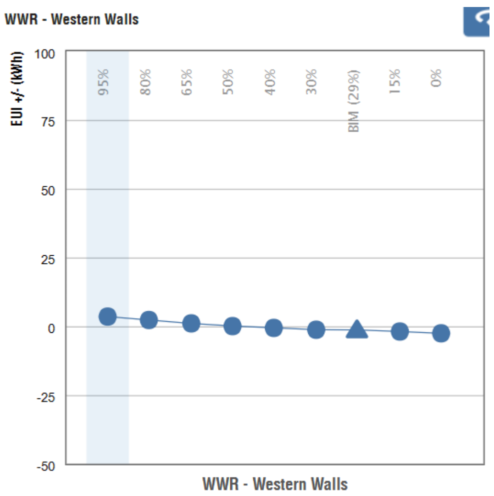


Figure 163 Image showing graph of EUI against WWR – Western Walls for Delta Chambers Building. Source: Author, 2023

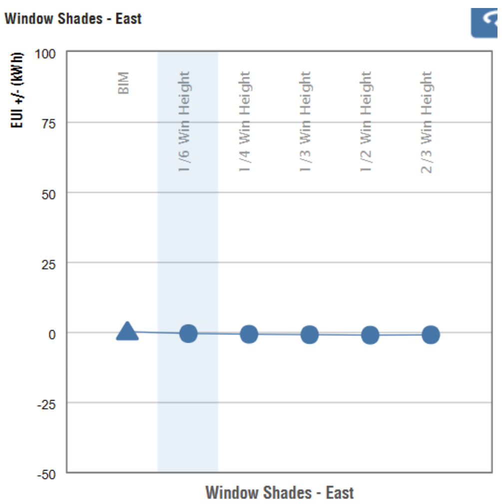


Figure 165 Image showing graph of EUI against Window Shades - East for Delta Chambers Building. Source: Author, 2023

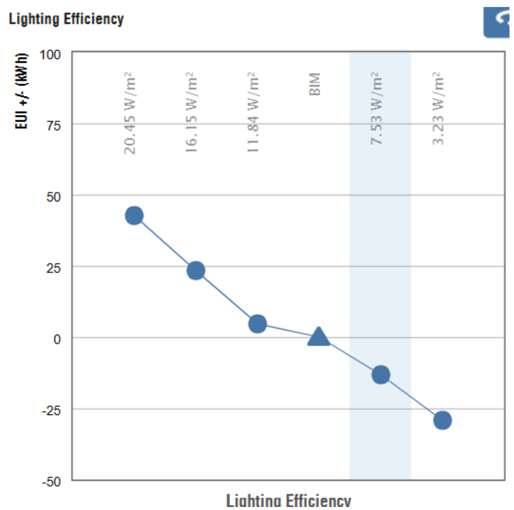


Figure 166 Image showing graph of EUI against Window Shades - South for Delta Chambers Building. Source: Author, 2023

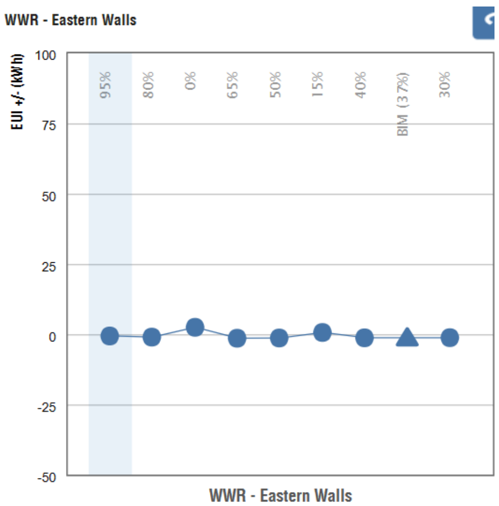


Figure 164 Image showing graph of EUI against WWR – Eastern Walls for Delta Chambers Building. Source: Author, 2023

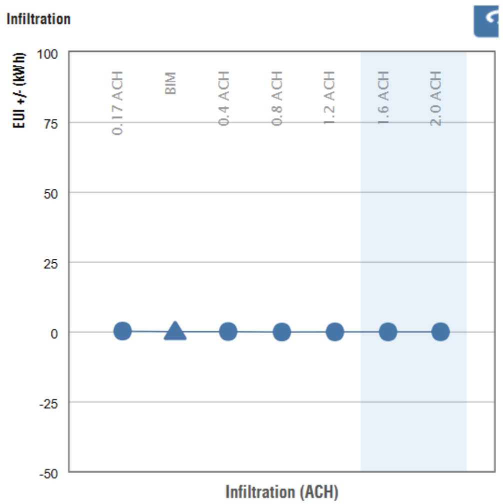


Figure 167 Image showing graph of EUI against Infiltration for Delta Chambers Building. Source: Author, 2023

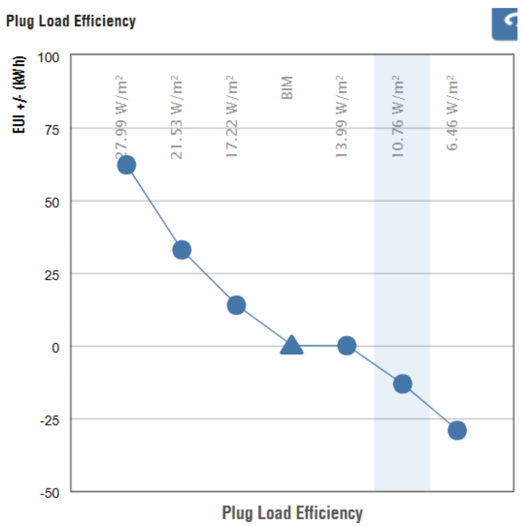


Figure 168 Image showing graph of EUI against Plug load Efficiency for Delta Chambers Building. Source: Author, 2023

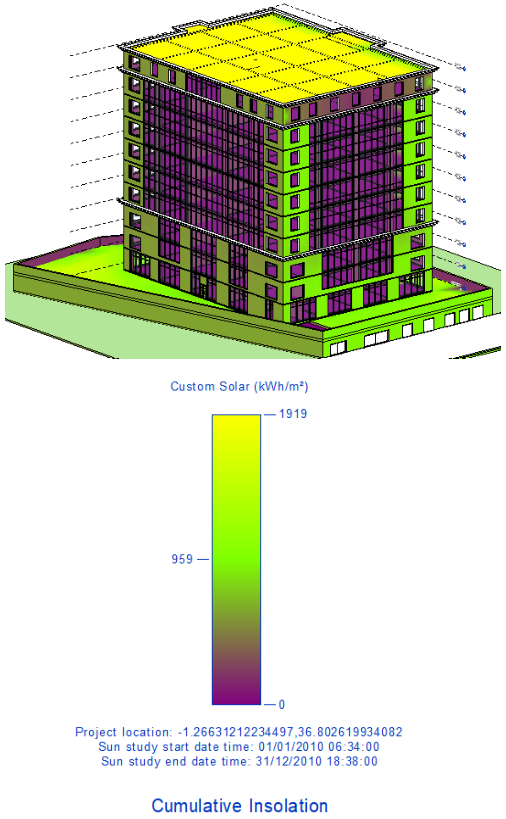


Figure 169 Image showing Solar analysis image for Delta Chambers Building

Source: Author, 2023

3 **Simulation** Analysis

The Benchmark comparison graph shown In Figure 154 shows a rate of 172 kwh/m2. Which is very high. The red colour indicates the energy use per m2 is way too high for the building. The following was also analysed from the graphs generated.

i. Building Orientation

The current building's orientation gives a very high energy use intensity. This is due to the glass cladding of the four elevations. Figure 155 shows the graph of EUI against the building orientation.

ii. Window Wall Ratio (WWR)

This depicts how the building's heating, cooling, and daylighting are affected by the window's characteristics. The WWR for buildings on matching facades may be calculated using the plots with the labels shown above. The window wall ratio for the Southern, Eastern, Western, and Northern walls is 95% which gives the building a very high mean cost. This makes the building perform poorly for the four walls. Figures 157, 163 and 164 show the EUI against the window wall ratio of the different walls.

iii. Window Shades

Window shades can be a useful tool for increasing a building's energy efficiency. The optimum shade for a given structure will depend on a variety of elements, including the environment, financial constraints, and personal preference. The current window shade as shown on the graph is 1/6 window height. The window glazing is not protected from direct sunlight making the building perform poorly. Figures 159, 160, 162, and 165 show the graphs of

EUI against window shades of the different walls.

i. Wall and Roof Construction

Due to a 95% glazing on the building, the building has a low thermal mass wall due to the characteristic of glass. This has allowed heat gain and loss from the building making it perform poorly. It is only the building's roof which is made of a thick slab offers some barrier to heat loss and gain to the building.

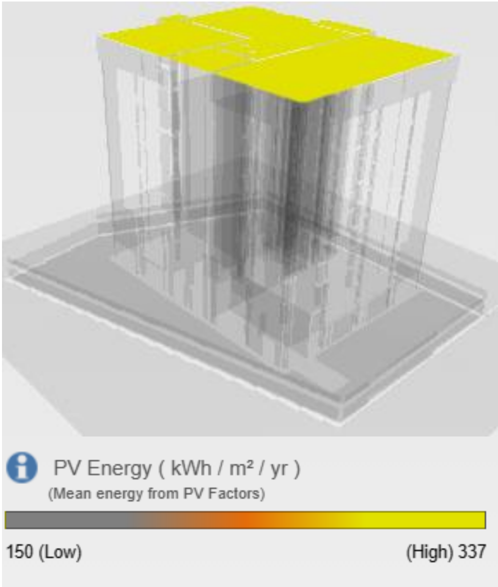


Figure 170 Image of Delta Chambers Building showing graph of EUI against HVAC Types

Source: Author, 2023

ii. Infiltration

The unintended leaking of air into and out of conditioned spaces is frequently caused by gaps in the building envelope. The current setting is 0.17 - 0.4 ACH. Figure 162 shows a graph of EUI against infiltration.

iii. Light Efficiency

It shows the typical interior heat gain and electric lighting energy usage per unit floor area. The current setting shows 20.45 W/m2 – 3.23 W/m2. This also causes glare to the interior of the building causing the use of blinds which ends up in the use of electricity during the day. Figure 166 shows a graph of EUI against lighting efficiency.

iv. Plug Load Efficiency

This is the energy used by less power-hungry gadgets like laptops and handheld electronics but not by heating, lighting, or cooling gadgets. The present configuration of the structure reads 27.99 W/m2 - 6.46 W/m2.

Figure 162 shows graph of EUI against plug load efficiency.

v. PV – Payback Limit

This demonstrates how to decide which areas will be utilized by the PV system by taking into account the payback period. Shady or poorly oriented solar surfaces may not be included. The 10-to-30-year range is currently displayed.

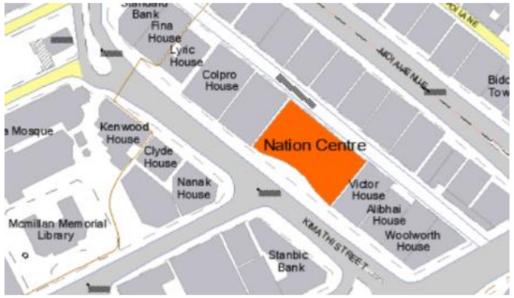


Figure 171 Location Map showing Delta Chambers. Source: Author adopted from JICA maps, 2023

Figure 172 Image of nation Centre.

Source: Author 2023

vi. PV – Surface Coverage

Specifies the maximum amount of roof space that may be utilized for PV panels, taking into account space for access for maintenance, rooftop equipment, and system infrastructure. The building's current settings range from 0% to 90%. This can produce 150–337 kWh/m2/Yr of PV energy.

4.6.2 Case Study 02: Energy Efficiency Analysis – Nation Centre, CBD, Nairobi

1. **Introduction**

Figure 173 map view of Nation Centre being analysed.

Source: Author adopted from google maps, 2023

The Nation Centre building is a well-known high-rise building in Nairobi, Kenya. It is located along Kimathi Street city's, major commercial district. it's the headquarters for the Nation Media Group. The building is a well-known landmark in Nairobi that is about 70 meters (230 feet) in height, with its distinctive shape and glass façade, it has a contemporary architectural style that makes it simple to identify. The building houses several facilities, including offices, newsrooms, broadcast studios, printing presses, and other media-related businesses. The building was designed by Planning System Ltd and Henning Larsen Tegnestue in 1986-87.

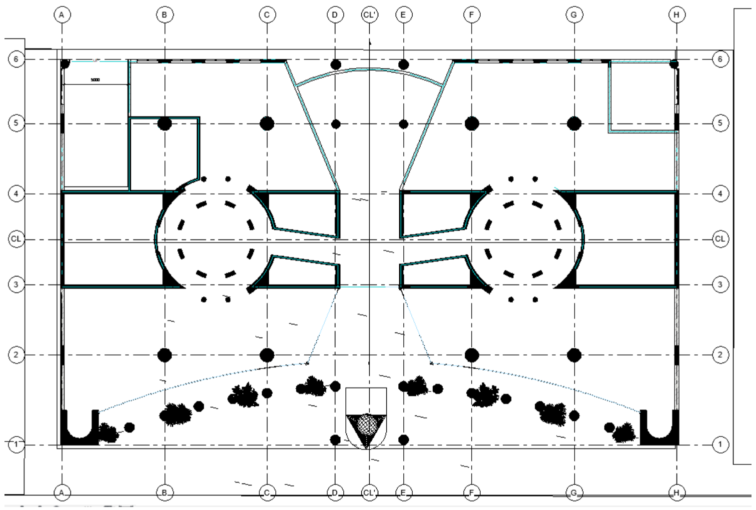


Figure 174 Image showing Ground Floor Plan of Nation Centre Building. Source: Author modified, 2023

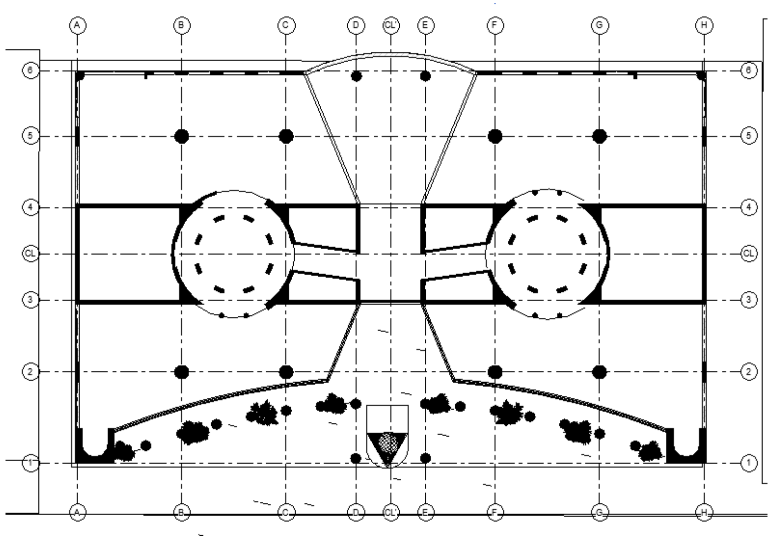


Figure 175 Image showing First Floor Plan of Nation Centre Building.

Source: Author modified, 2023

Parameters assessed for energy efficiency for Nation Centre building are highlighted below:

1. Site Selection: the building's orientation is minimally tilted from the East-West axis. The podium's glazed openings are protected with louvers.
2. Site Planning: the building rising high above the neighbouring building helps in taking advantage of the wind for natural ventilation. The adjacent buildings protect the podium from direct sunlight.
3. The building form; the building has two circular towers. The glazing on the towers is not adequately shaded from direct sunlight. The ground floor has an arcade that promotes cross ventilation therefore naturally cooling the podium.
4. Building plan and appropriate space organization: the building's service areas are located on the East and West facades protecting the interior from direct sunlight. The form is emphasised with white and green stripes.
5. Building Envelope: the building's gazing on the podium is protected with louvers. Most of the glazed elevations are not exposed to direct sunlight. There are operable windows that allow for natural ventilation.
6. Choosing energy-efficient building materials: Most of the materials used have been locally sourced, they are durable and can be recycled.
7. Energy Efficient Landscape Designs: this has not been done effectively.
8. Use of Renewable Energy resources; this has not been utilised in in this project.
9. Occupancy: the building's occupancy is also at 75%. The building is more than 30 years old since it was constructed and is still competing for tenants with other new buildings in the CBD.

2. Simulation Results

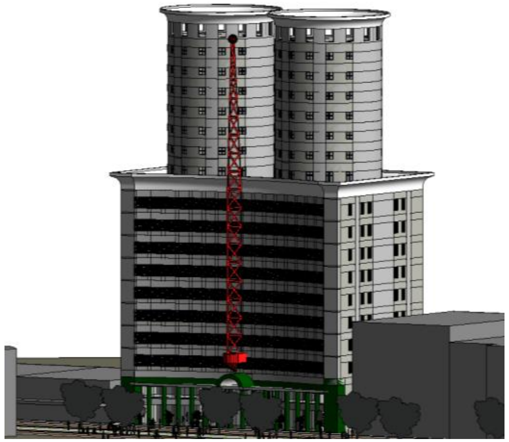


Figure 176 Image of Nation Centre Building.

Source: Author, 2023

Figure 177 Image of generated analytical model of Nation Centre Building.

Source; Author, 2023

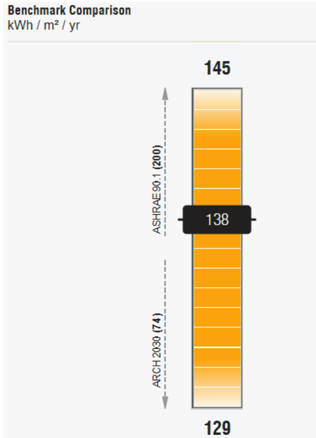


Figure 178 Image of Nation Centre showing Bench Comparison from the simulation.
Source: Author, 2023

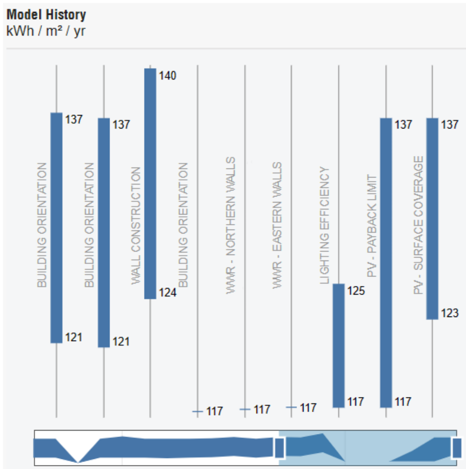


Figure 180 Image of Nation Centre showing Bench Comparison from the simulation.
Source: Author, 2023

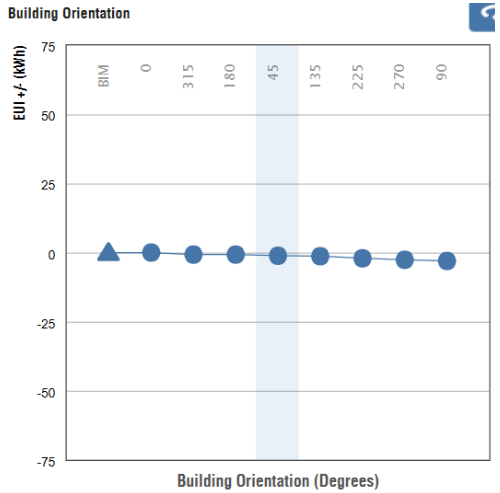


Figure 179 Image of Nation Centre Building showing graph of EUI against Building Orientation
Source: Author, 2023

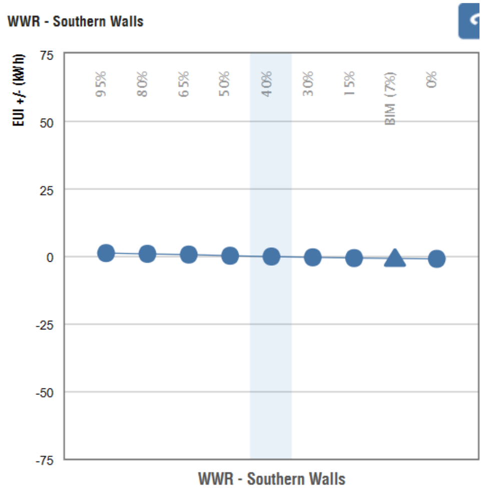


Figure 181 Image of Nation Centre showing graph of EUI against Southern Walls.
Source: Author, 2023

Figure 182 Image of optimized analytical model of Nation Centre Building.

Source; Author, 2023

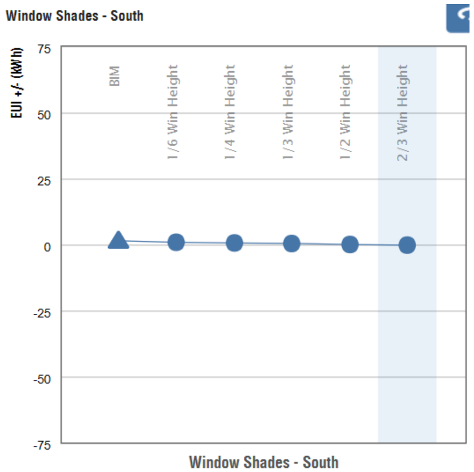


Figure 183 Image of Nation Centre showing graph of EUI against Window Shades - South.
Source: Author, 2023

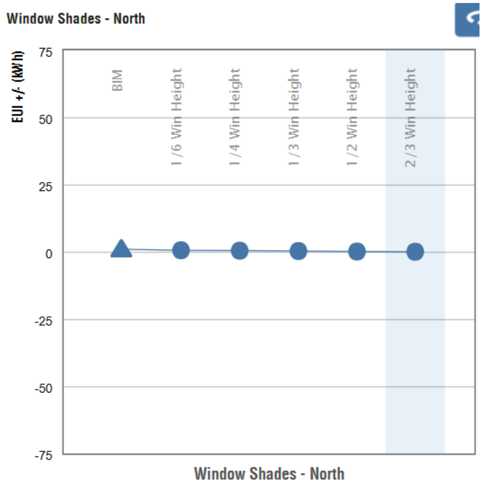


Figure 184 Image of Nation Centre showing graph of EUI against Window Shades - North.
Source: Author, 2023

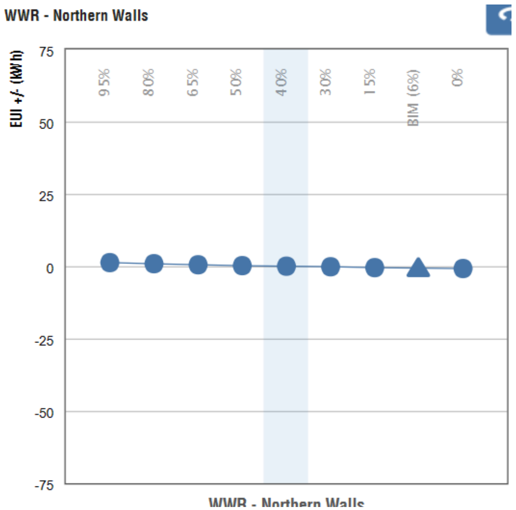


Figure 185 Image of Nation Centre showing graph of EUI against Northern Walls.
Source: Author, 2023

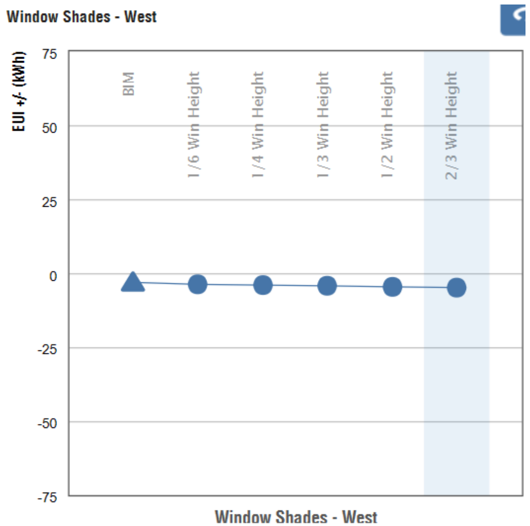


Figure 186 Image of Nation Centre showing graph of EUI against Window Shades - West.
Source: Author, 2023

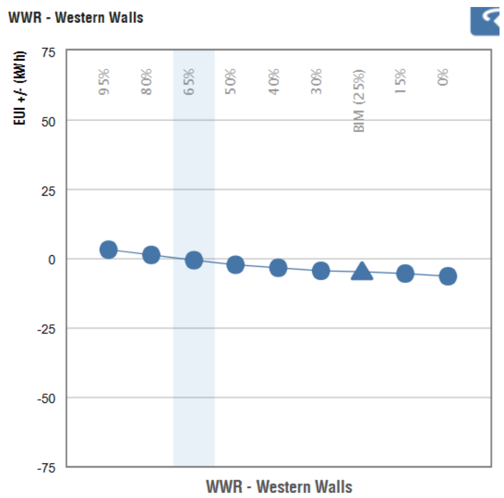


Figure 187 Image of Nation Centre showing graph of EUI against WWR – Western Walls.
Source: Author, 2023

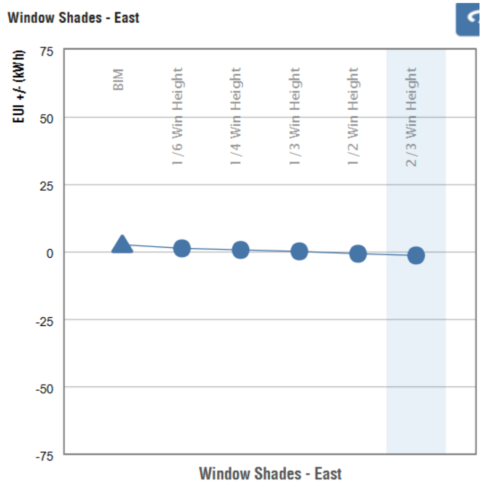


Figure 189 Image of Nation Centre showing graph of EUI against Window Shades – East.
Source: Author, 2023

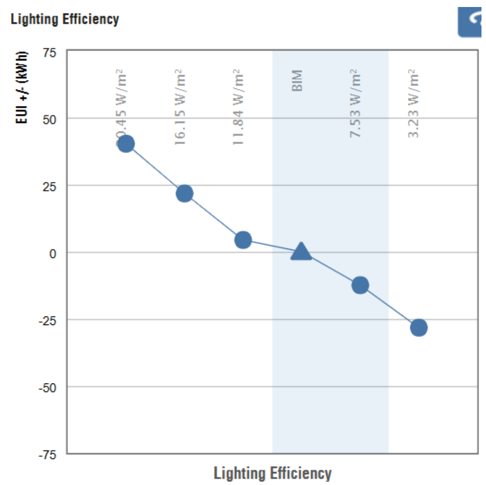


Figure 190 Image of Nation Centre showing graph of EUI against Lighting Efficiency.
Source: Author, 2023

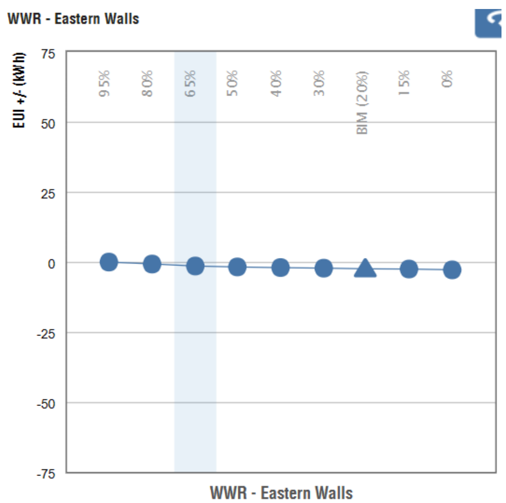


Figure 188 Image of Nation Centre showing graph of EUI against WWR – Western Walls.
Source: Author, 2023

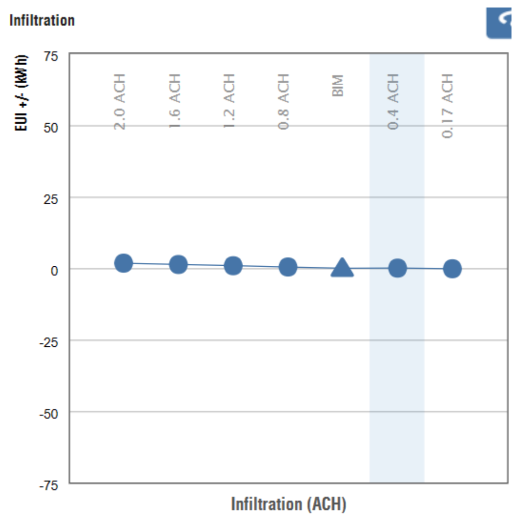


Figure 191 Image of Nation Centre showing graph of EUI against infiltration.
Source: Author, 2023

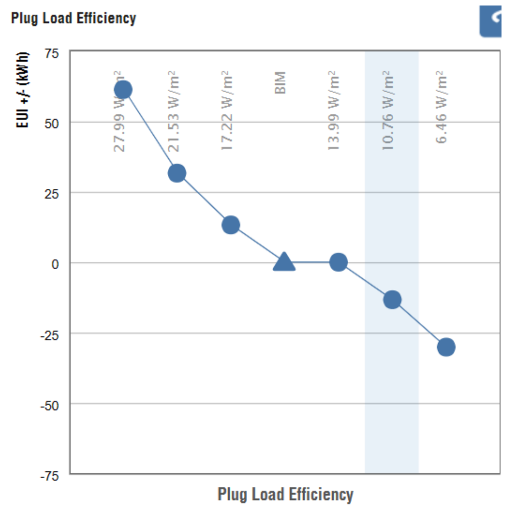


Figure 192 Image of Nation Centre showing graph of EUI against plug load Efficiency.
Source: Author, 2023

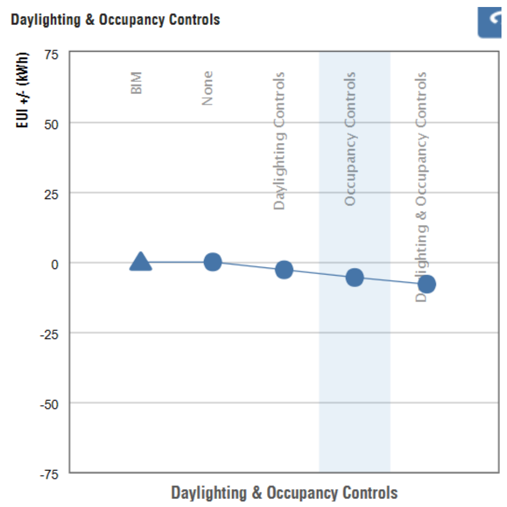


Figure 193 Image of Nation Centre showing graph of EUI against Daylighting and Occupancy Controls.
Source: Author, 2023

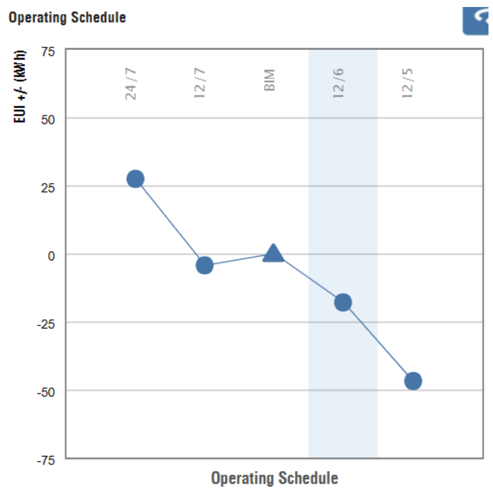


Figure 195 Image of Nation Centre showing graph of EUI against Operating Schedule
Source: Author, 2023

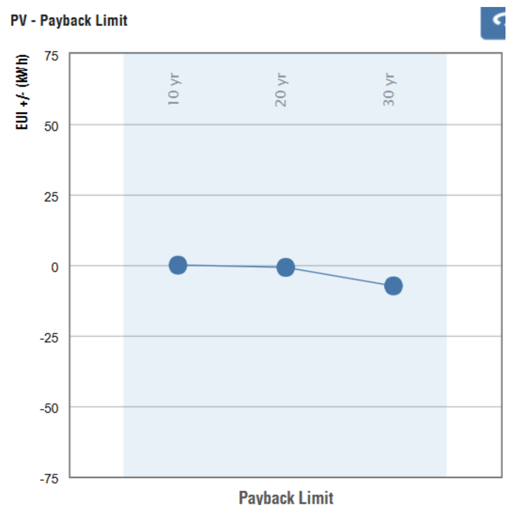


Figure 196 Image of Nation Centre showing graph of EUI against Payback Limit.
Source: Author, 2023

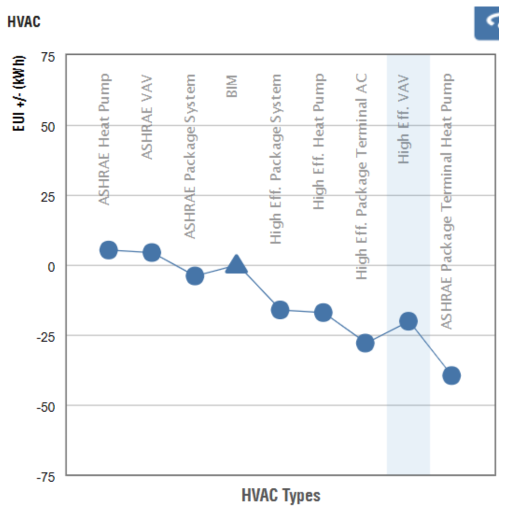


Figure 194 Image of Nation Centre showing graph of EUI against HVAC Types
Source: Author, 2023

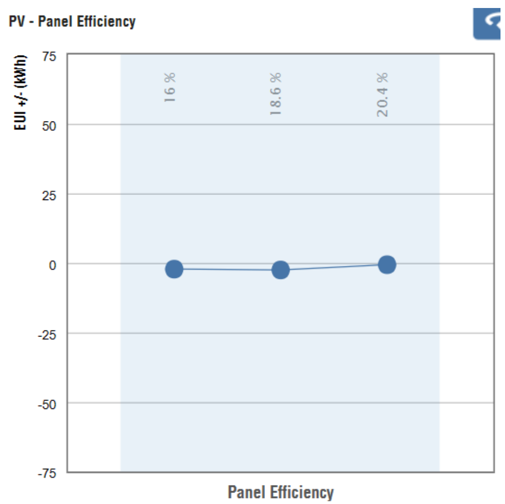


Figure 197 Image of Nation Centre showing graph of EUI against PV Panel Efficiency
Source: Author, 2023

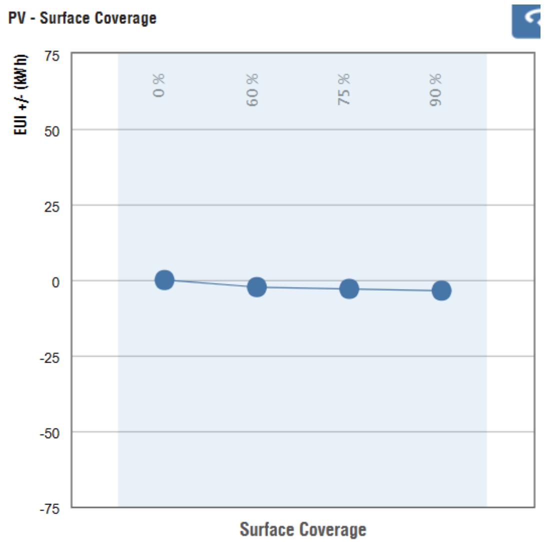


Figure 198 Image of Nation Centre showing graph of EUI against PV – Surface Coverage
Source: Author, 2023

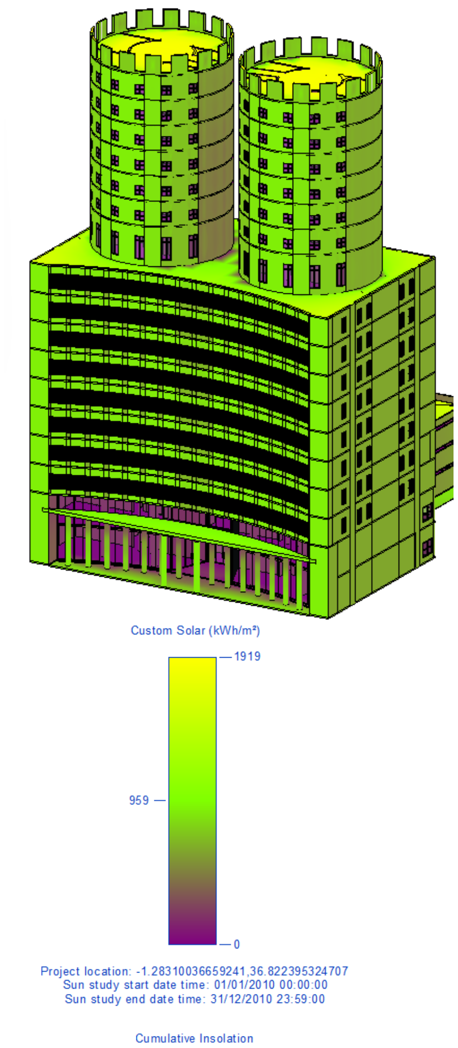


Figure 199 Image showing Solar analysis image for Nation Centre Building.

Source: Author, 2023

3. Simulation Analysis

The Benchmark comparison graph shown in Figure 178 shows a rate of 138 kwh/m2. Which is very high. energy use per m2 is way below the first case. The following was also analysed from the graphs generated.

i. Building Orientation

The current building’s orientation gives a lower energy use intensity compared to the first case where we had a fully glass cladded building. Editing the building’s orientation towards the East and West axis reduces the cost significantly. Figure 179 shows the graph of EUI against the building orientation.

ii. Window Wall Ratio (WWR)

This depicts how the building's heating, cooling, and daylighting are affected by the window's characteristics. The graphs with the labels above can be used to determine the WWR on corresponding facades. Figures 181, 183, 187, and 188 show the graphs of EUI against WWR of the different facades of the building. WWR for the Southern wall is at 15% which gives the building a lower mean cost. The WWR for the Northern wall is at 40%, the west at 25% and the East wall at 30%. This makes the building perform better compared to the first case of the glass-cladded building.

iii. Window Shades

Window shades can be a useful tool for increasing a building's energy efficiency. The optimum shade for a given structure will depend on a variety of elements, including the environment, financial constraints, and personal preference. Figures 184, 186, and 189 show the graphs of EUI against window shades of the building.

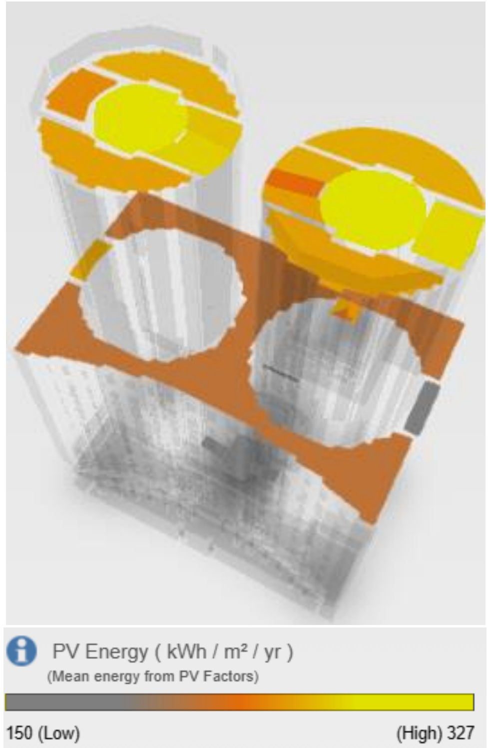


Figure 200 Image of ICEA Building showing graph of EUI against HVAC Types

The current window shade as shown on the graph is 2/3 window height which is optimal for this case.

iv. Wall and Roof Construction

The building has a high thermal mass wall. This has helped to resist heat gain and loss. The building's roof which is made of a thick slab is a barrier to heat loss and gain to the building.

v. Infiltration

This is the unintended air leakage into and out of climate-controlled areas, which is frequently caused by openings in the building's envelope. The current value is 0.4 ACH at the moment. Figure 191 shows the graph of EUI against infiltration.

vi. Lighting Efficiency

It shows the typical interior heat gain and electric electricity usage per unit floor area. The current setting shows 7.53 W/m2.

vii. Plug Load Efficiency

This is the electricity consumed by less power-hungry devices, such as laptops and small appliances, but not by devices for lighting, heating, or cooling. The current setting for the building shows 10.76 W/m2.

viii. PV – Payback Limit

This shows the use of the payback period to define which surfaces will be used for the PV system. Surfaces with shading or poor solar orientation may be excluded. Figure 196 shows the graph of EUI against PV – Payback limit. The setting shows 10-30 years.

Figure 201 Location Map showing ICEA Building. Source: Author adopted from JICA maps, 2023

Figure 202 Image of ICEA Building, CBD, Nairobi Kenya.

Source: Author 2023

ix. PV – Surface Coverage

Outlines the maximum amount of roof space that may be utilized for solar panels, taking servicing accessibility, roof machinery, and system infrastructure with account. Figure 198 shows the graph of EUI against PV – Surface Coverage. The setting for the building shows 0%-90%.

4.6.3 Case Study 03: Energy Efficiency Analysis –ICEA BUILDING, (JKUAT TOWERS) CBD, Nairobi

1. **Introduction**

Figure 203 map view of ICEA Building being analysed.

Source: Author adopted from google maps, 2023

The ICEA building was completed in 1981. It was designed by Arch. Richard Hughes. It is a 19-storey building originally designed for general offices and retail on the podium. Currently, the building houses the Jomo Kenyatta University of Technology, City campus.

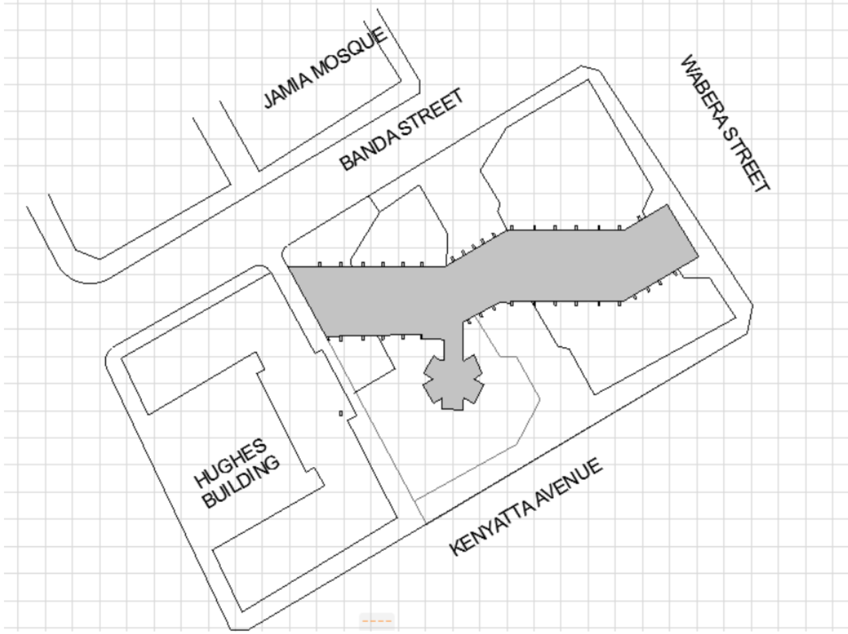


Figure 204 Image showing Site Plan of ICEA Building.
Source: Author, 2023

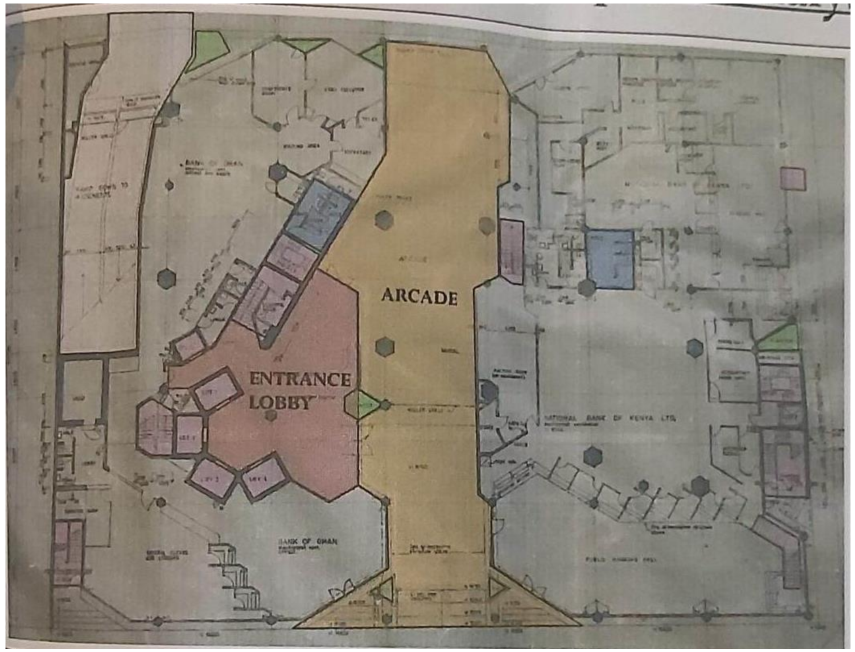


Figure 205 Image showing Ground Floor Plan of ICEA Building.
Source: Architect Richard Hughes

Parameters assessed for energy efficiency for the ICEA building are highlighted below:

1. Site Selection: the building's orientation is the East-West axis.
2. Site Planning: the building orientation is narrow with the East and West axis with the long facades facing north and South. The building also rises high above the neighbouring building taking advantage of the wind for natural ventilation.
3. The building form; the building is narrow. There is minimal glazing on the East and West facades. More than 90 % of the glazing is on the South and North facades. The glazing is adequately shaded from direct sunlight with sun-shading devices. The ground floor has an arcade that promotes cross ventilation therefore naturally cooling the podium.
4. Building plan and appropriate space organization: the building's service areas are located on the East and West facades protecting the interior from direct sunlight. The form is emphasised with light colours that reflect sunlight helping the building to remain cool during the day.
5. Building Envelope: the building's gazing is protected with louvers. Openings are protected from direct sunlight with overhangs and louvers. There are operable windows that allow for natural ventilation.
6. Choosing energy efficient building materials: Most of the materials used have been locally sourced, they are durable and can be recycled.
7. Energy Efficient Landscape Designs: this has not been done effectively.
8. Use of Renewable Energy resources; this has not been utilised in in this project.
9. Occupancy: the building's occupancy is at 70%. The building is more than 40 years old since it was constructed and still competing for tenants with new buildings

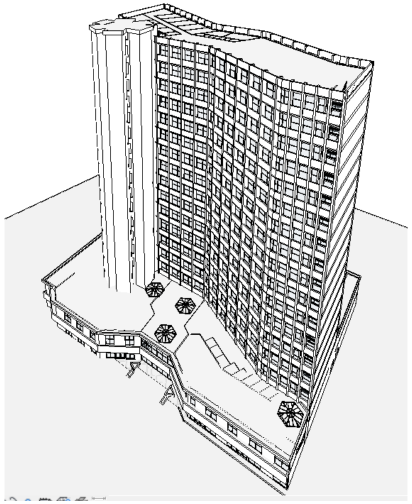


Figure 206 Image of ICEA Building model.

Source: Author, 2023

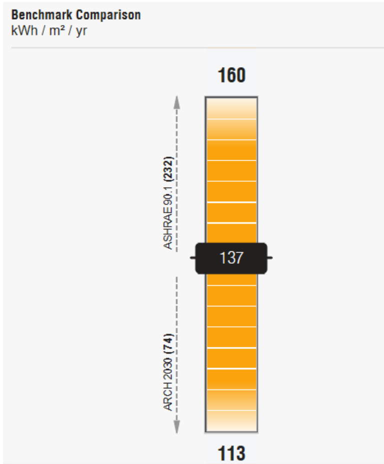


Figure 208 Image of ICEA Building showing graph of Benchmark Comparison
Source: Author, 2023

2. Simulation Results

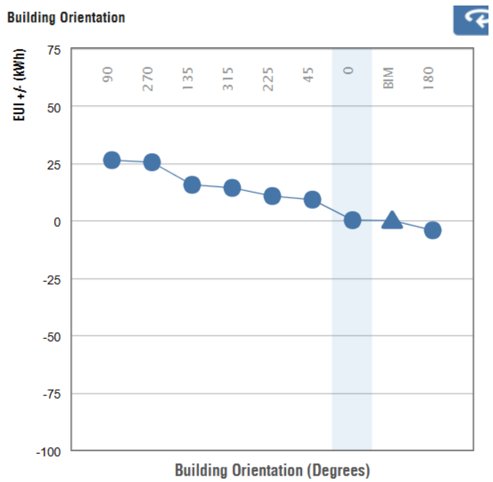


Figure 209 image of ICEA Building showing graph of Building Energy Use Intensity against Building Orientation
Source: Author, 2023

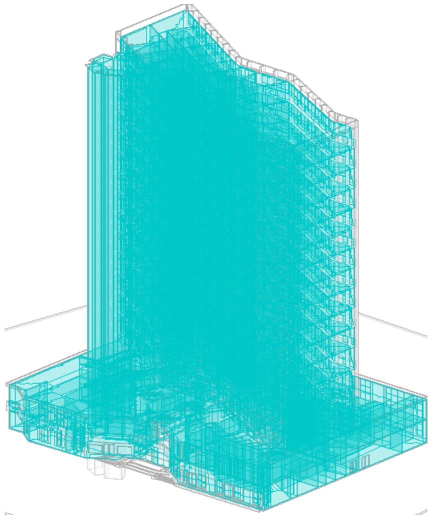


Figure 207 Image of ICEA Building analytical space model.

Source: Author, 2023

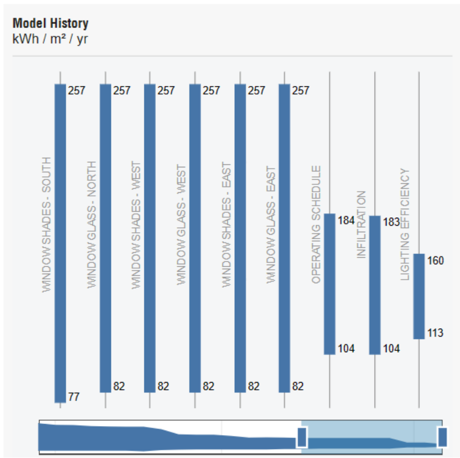


Figure 210 image of ICEA Building showing graph of Model History
Source: Author, 2023

Figure 211 Image of ICEA Building showing graph of EUI against WWR – Southern Walls
Source: Author, 2023

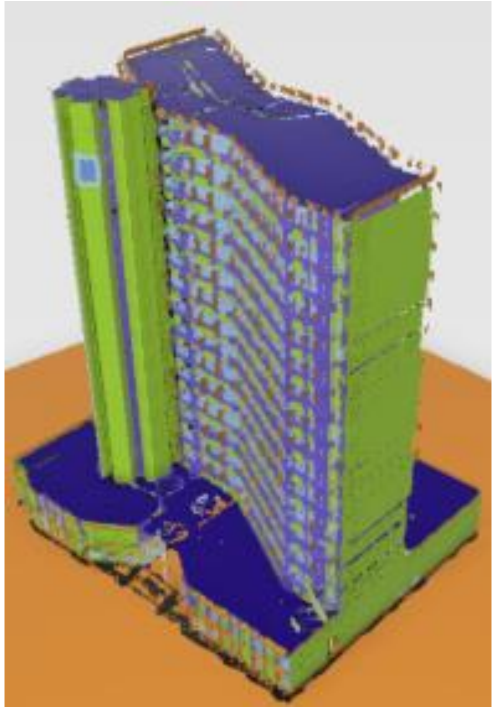


Figure 212 Image of ICEA Building showing PV analysis for use.

Source: Author generated from Autodesk Insight

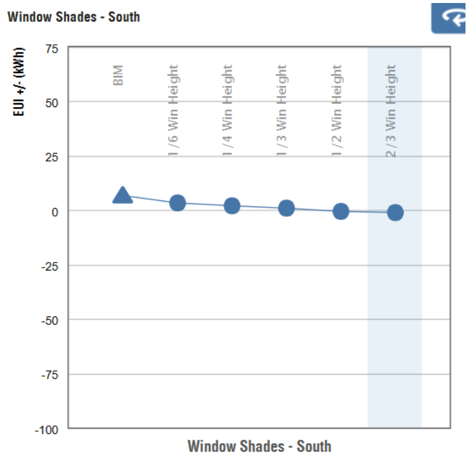


Figure 213 Image of ICEA Building showing graph of EUI against Window Shades - South Walls
Source: Author, 2023

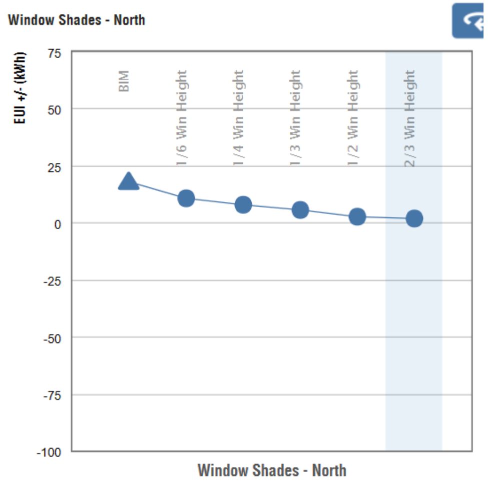


Figure 214 Image of ICEA Building showing graph of EUI against Window Shades – North

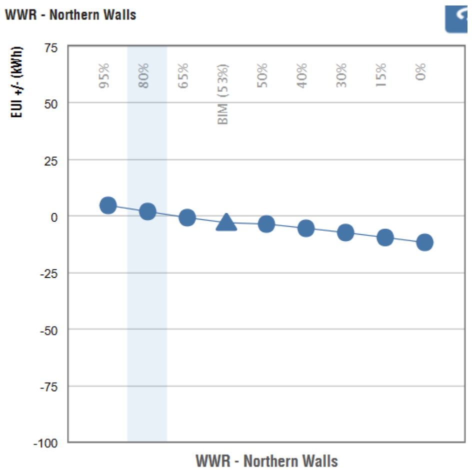


Figure 215 Image of ICEA Building showing graph of EUI against WWR – Northern Walls.
Source: Author, 2023

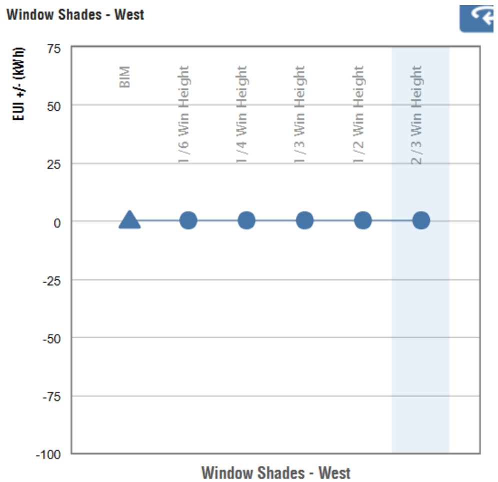


Figure 216 Image of ICEA Building showing graph of EUI against Window Shades - East
Source: Author, 2023

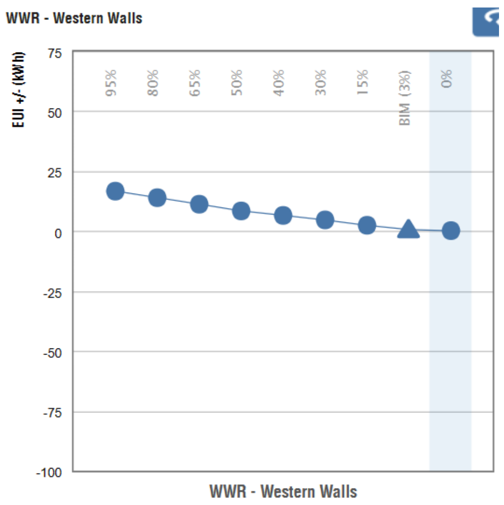


Figure 217 Image of ICEA Building showing graph of EUI against WWR - Western Walls
Source: Author, 2023

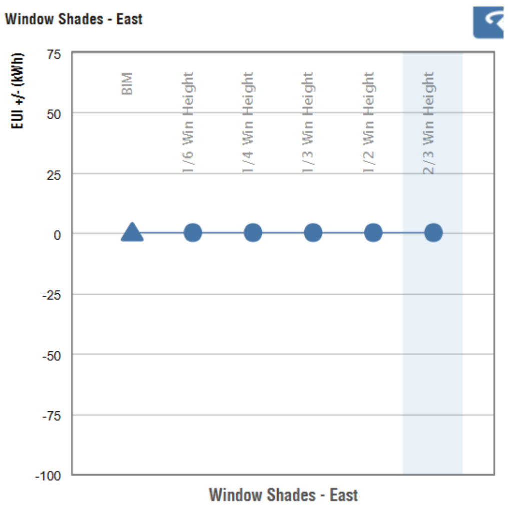


Figure 219 Image of ICEA Building showing graph of EUI against Window Shades - East
Source: Author, 2023

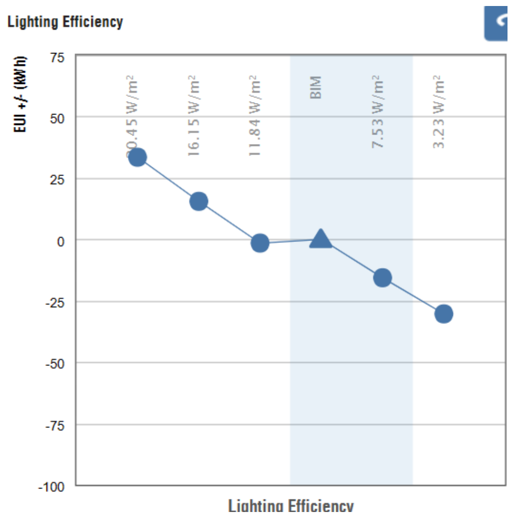


Figure 220 Image of ICEA Building showing graph of EUI against Lighting Efficiency

Source: Author, 2023

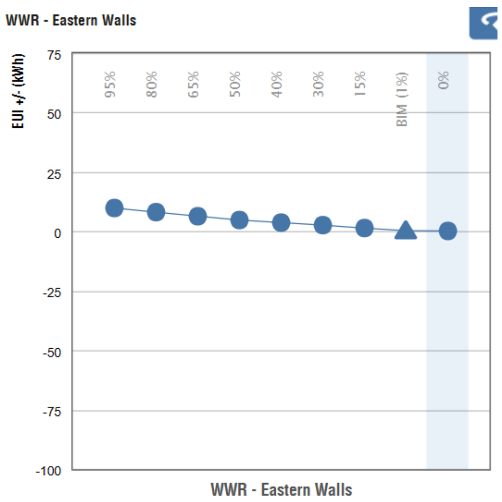


Figure 218 Image of ICEA Building showing graph of EUI against WWR – Eastern Walls
Source: Author, 2023

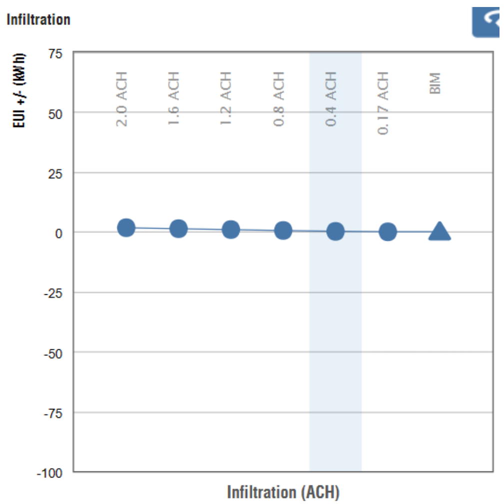


Figure 221 Image of ICEA Building showing graph of EUI against Infiltration
Source: Author, 2023

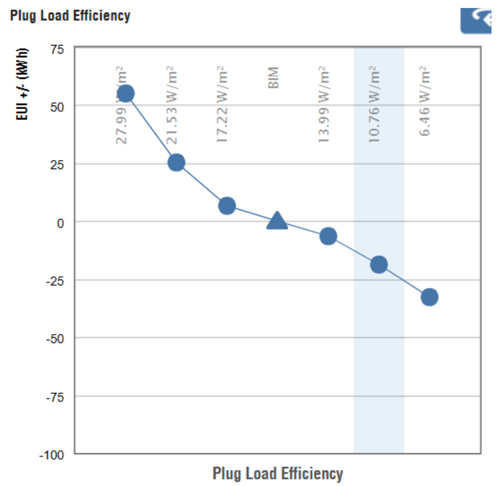


Figure 222 Image of ICEA Building showing graph of EUI against Plug Load Efficiency
Source: Author, 2023

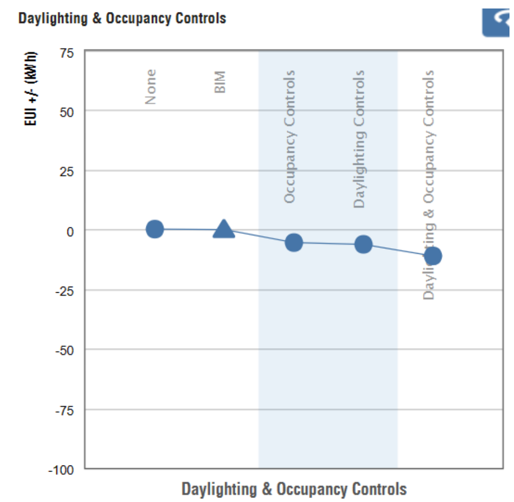


Figure 223 Image of ICEA Building showing graph of EUI against Daylighting and Occupancy Controls
Source: Author, 2023

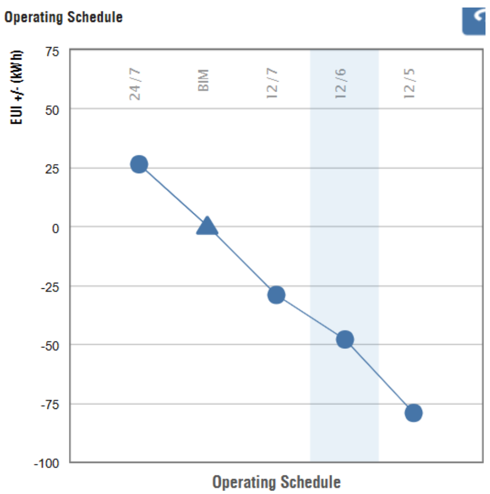


Figure 225 Image of ICEA Building showing graph of EUI against Operating Schedule
Source: Author, 2023

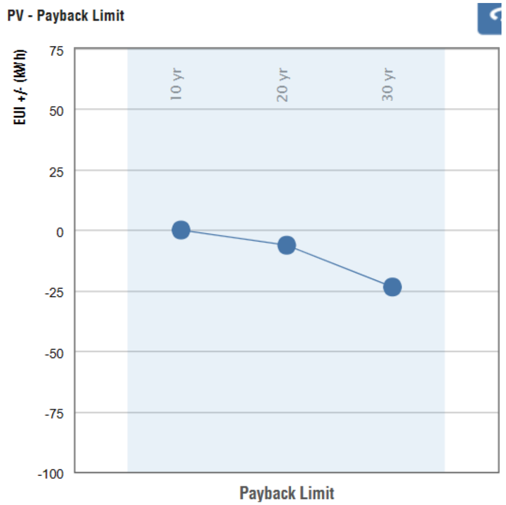


Figure 226 Image of ICEA Building showing graph of EUI against Payback Limit
Source: Author, 2023

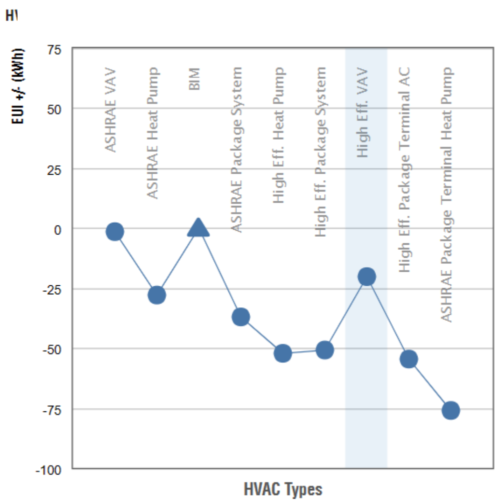


Figure 224 Image of ICEA Building showing graph of EUI against HVAC Types
Source: Author, 2023

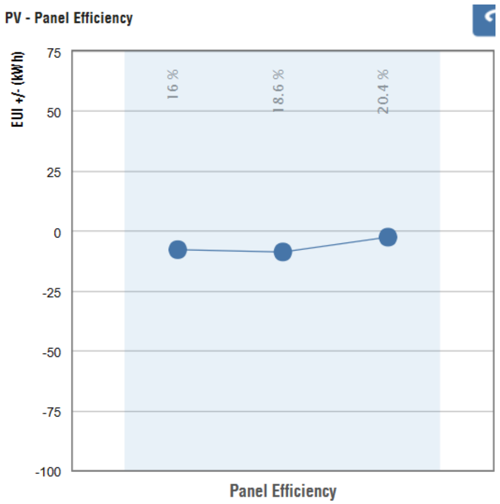


Figure 227 Image of ICEA Building showing graph of EUI against PV Panel Efficiency
Source: Author, 2023

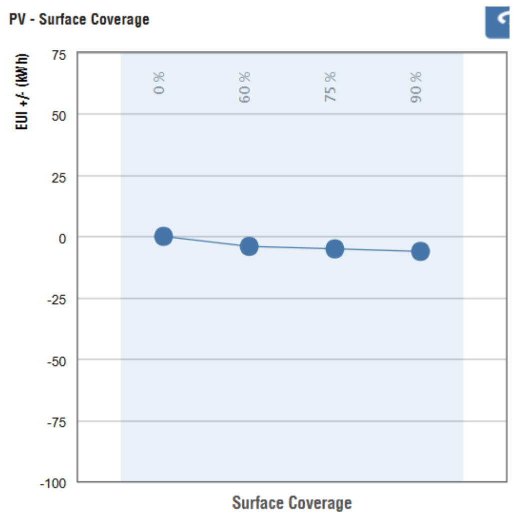


Figure 228 Image of ICEA Building showing graph of EUI against PV Surface Coverage
Source: Author, 2023

Figure 229 Image showing Solar analysis image for ICEA building.

Source: Author, 2023

3. **Simulation Analysis**

The Benchmark comparison graph shown in Figure 208 shows a rate of 137 kwh/m2/Yr. Which is the lowest compared to the other EUI the first and second case studies. The following was also analysed from the graphs generated.

i. Building Orientation

The current building's orientation gives an Energy mean of 12.0 kWh/M2/Yr. The building's tower is on the East–West axis with long facades facing South and North. Figure 209 shows the graph of EUI against the building orientation.

ii. Window Wall Ratio

This depicts how the building's heating, cooling, and daylighting are affected by the window's characteristics. The graphs with the labels above can be used to determine the window-wall ratio for walls on corresponding faces. Figures 211, 215, 217, and 218 show the graph of EUI against the WWR. The window wall ratio for the Southern and Northern walls is at 80% and well shaded, which has a rating of 150kWh/m2/yr. the Eastern and Western walls do not have glazing. This makes the building perform well generally.

iii. Window Shades

Window shades can be a useful tool for increasing a building's energy efficiency. The optimum shade for a given structure will depend on a variety of elements, including the environment, financial constraints, and personal

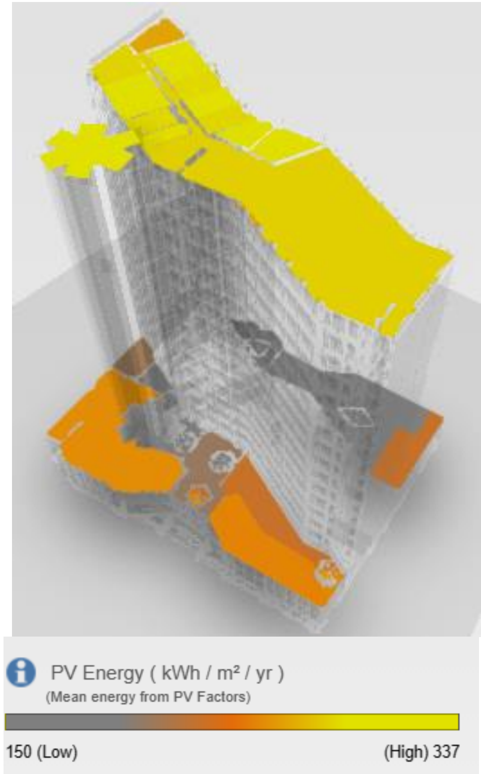


Figure 230 Image of ICEA Building showing PV analysis for use.

Source: Author generated from Autodesk Insight

preference. Figures 213, 214, 216, and 219 show the graph of EUI against the window shades of the building. The current window shade as shown on the graph is 2/3 window height which is optimal for this case. The window glazing is protected from direct sunlight with sun shaders.

iv. Wall and Roof Construction

The building is well protected from direct sunlight. This has enabled the building to perform well. the thick walls on the East and West facades and a thick flat roof slab resist loss and heat gain to the building.

v. Infiltration

This is the unintended air leakage into and out of climate-controlled areas, which is frequently caused by openings in the building skin. The setting at the moment is 0.4 ACH. Figure 221 shows the graph of EUI against infiltration. The lower it can get, the better performance we can get.

vi. Lighting Efficiency

The usual indoor thermal gain and lighting power consumption per floor area. The current setting shows 7.53 W/m2.

vii. Plug Load Efficiency

This is power used by equipment that consumes less power like computers and small appliances excluding lighting heating and cooling equipment. Figure 222 shows the graph of EUI against plug load efficiency. The current setting for the building shows 10.76 W/m2.

viii. PV – Payback Limit

This demonstrates how to decide which surface will be utilized by the PV system by taking into account the payback period. Shady or poorly oriented solar surfaces may not be included. Figure 226 shows the graph of EUI against PV – payback limit. The 10-to-30-year range is currently displayed.

ix. PV – Surface Coverage

Specifies the maximum amount of roof space that may be utilized for PV panels, taking into account space needed for infrastructure, rooftop equipment, and maintenance access. Figure 222 shows the graph of EUI against PV – Surface coverage. The building's current settings range from 0% to 90%.

4.7 Summary of Findings

Buildings with glass facades and high Window wall ratio let in a lot of light and provide views. However, glass, on the other hand, performs poorly as an insulator, causing significant thermal heat gain from direct sunlight and raising cooling demands.

Glass-cladded buildings frequently rely extensively on mechanical cooling systems, such as air conditioning, which use a lot of energy, to reduce heat absorption. Energy usage and related greenhouse gas emissions increase as a result of the requirement for air conditioning.

Bio-climatically designed buildings attain energy efficiency, by taking advantage of the local climate and natural resources. Emphasis is put on passive design methods that reduce dependency on mechanical systems.

Bioclimatic design concepts place a strong emphasis on sun shading, natural ventilation, and optimizing building orientation to prevent heat gain in tropical areas. High ceilings, cross ventilation, well-placed openings, and passive cooling methods like evaporative cooling can all help achieve this. Buildings designed for bioclimatic environments frequently have shading features like overhangs, fins, or plants to block the sun's rays and lower solar heat gain. With less reliance on mechanical cooling systems, these characteristics aid in preserving pleasant indoor temperatures.

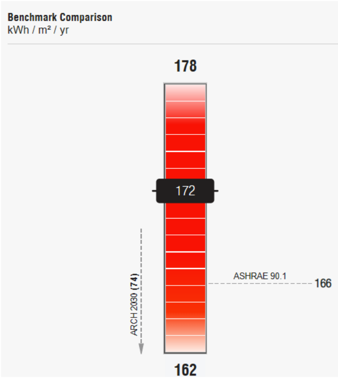
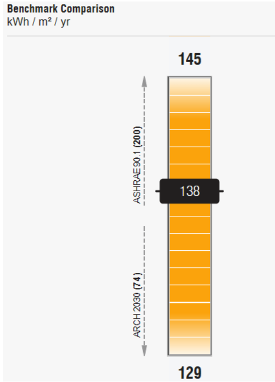
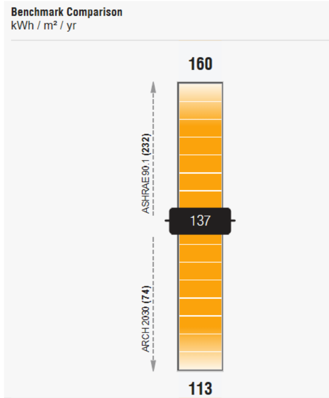
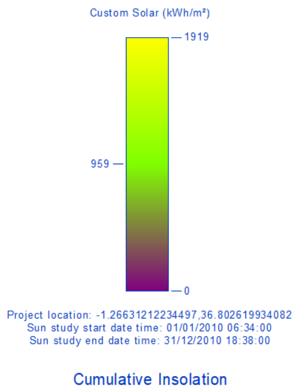
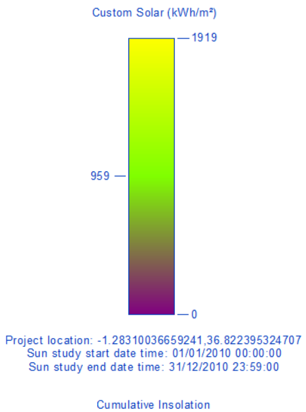
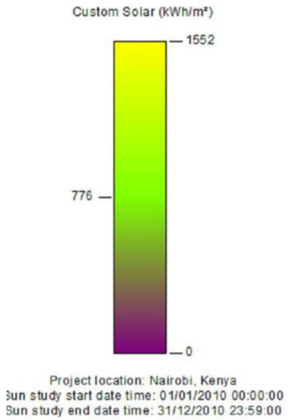
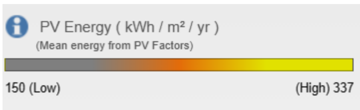
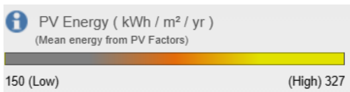
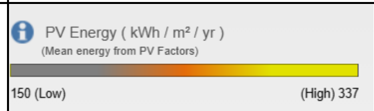
BUILDING	DELTA CHAMBERS BUILDING	NATION CENTRE BUILDING	ICEA BUILDING	COMMENTS
Benchmark Comparison (Kwh/M2/Yr)				• Delta Chambers shows a higher Benchmark comparison of 172Kwh/M2/R compared to Nation Centre Building and ICEA Building which have a 138 and 137 Kwh/M2/Yr. respectively. • The glass cladded building performs poorly causing significant thermal heat gain from direct sunlight and raising cooling demands.
Solar Analysis				• Delta Chambers shows a higher cumulative insolation. This means it receives more solar energy on the surface because of the use of glass facades. The other two buildings show less energy received that the first case.
Pv Energy ((Kwh/M2/Yr)				• The three case studies have the same PV energy meaning they have the same potential for renewable solar energy.

Table 6 shows the comparison of summary of the three Case Studies

Overall, glass-covered buildings can be attractive and seem open, but they may also have problems with noise, glare, and thermal comfort. On the other hand, bio-climatically designed buildings emphasize the creation of comfort and healthy indoor spaces through passive design techniques, the optimization of thermal conditions, and taking into account occupant well-being. The tenant experience in bioclimatic buildings may be improved by taking these aspects into account. Table 6 shows the comparison summary of the three case studies.

4.8 Building Energy Benchmarking Model

Comparing a structure's energy consumption to that of other structures of a similar kind or that meet predetermined energy efficiency standards is known as "building energy benchmarking." When a building is benchmarked, its ability to conserve energy is assessed, areas for enhancement are identified, and decisions are taken to maximize energy consumption and save costs.

The following steps are typically used in the process:

1. Data collection: Compile data on the amount of natural gas, electricity, fuel oil, and different energy sources used by the building. Weather data, patterns of occupancy, and building characteristics (such as floor area, occupancy, and working hours) may also be collected.
2. Normalization: Adjust the statistics of energy usage to take into account fluctuations in factors, such as weather conditions and capacity levels, that affect the consumption of energy but are outside the building's control. This enables fair comparisons of different constructions independent of their location or intended function.
3. 3. Benchmark comparison: Compare the structure's energy efficiency to industry norms, norms set by authorities, or programs aimed at enhancing energy efficiency. The comparison of points might be established using similar building types, climatic zones, or other relevant factors.

4. Analyse the benchmarking results to identify any spaces where the energy efficiency of the structure is below industry standards or benchmarks. These locations could have outdated machinery, poor insulating material, HVAC systems, or inefficient lighting.
5. Goal-setting: Relying on the benchmarking information, set acceptable energy efficiency objectives for the facility. These objectives must take into consideration factors like return on investments and building occupancy and be consistent with the targets for lowering energy usage.
6. Carry out energy-efficient improvements and actions to capitalize on the potential for development that has been recognized. This might mean incorporating smart building technologies, improving insulation, installing energy-efficient lighting, or upgrading HVAC systems.
7. Monitoring and assessment: After implementing energy-saving measures, monitor and record energy use. Regularly evaluate the performance of the structure with respect to the set objectives to track advancement and identify new areas for improvement.

05 Conclusions and Recommendations

Chapter Five

2.0 Introduction

2.1 Conclusion Based on Chapters

2.2 Conclusion Based on Objectives of the Study

2.3 Recommendations

2.4 Areas of Further Research

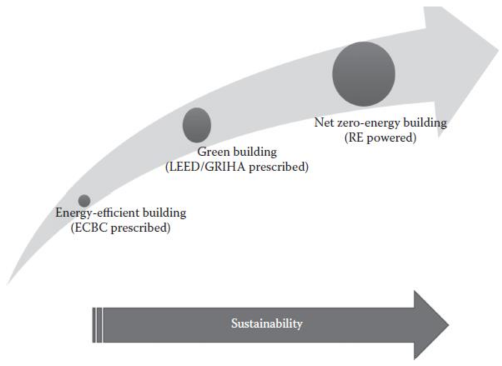


Figure 231 Image showing the idea of sustainability as a scale which is dependent on time and space. Source: Sustainability through Energy-Efficient Buildings

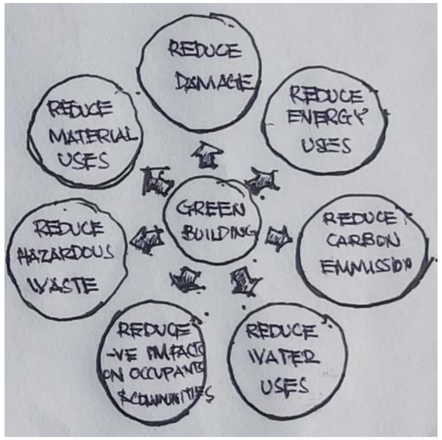


Figure 232 Image showing the benchmark of green building based on reducing negative impacts. Source: Author modified, 2023

5.0 Introduction

This study aims to investigate the energy efficiency and occupancy levels of glass-cladded buildings and bio-climatically designed buildings in Nairobi. This chapter discusses the study's conclusions and suggestions to provide a summary of the research's lessons learned. The concepts derived from the theoretical discussion, collection of data, and analysis are summarised in this chapter. To design buildings that are comfortable, healthy, and environmentally conscious while promoting a sustainable lifestyle, the goal is to draw conclusions based on energy efficiency and occupancy levels of glass-cladded and bioclimatic buildings. Recommendations are put forth based on the findings of this investigation.

5.1 Conclusions Based on Chapters

5.1.1 Chapter I: Introduction

The introduction defines the context of this research's inspiration, that is energy-efficient buildings in tropical climates for a safe, secure, and sustainable environment. The requirement for CO_2 emission reductions of 30% targets by 2030. It has also outlined the issue that needs to be researched to design buildings that are climate responsive, for tropical regions, and energy-efficient buildings due to the resource depletion and impacts of pollution. This was done following the formulation of the study questions and the research's goals. The first chapter serves as the thesis' introduction and lays out the study's clear direction as well as its research strategy. The background information justifies the research topic and shows how the phenomena in the problem could be the basis for the investigation.

investigation.

5.1.2 Chapter II: Literature Review

Figure 233 Image showing Anniversary Building Nairobi. Source: Bing images, 2023

The background to the development of energy-efficient buildings was covered in this chapter. It has looked at buildings that were energy-efficient in the twentieth century, a time when the 1973 oil crisis resulted in a huge movement toward creating energy-efficient structures. Figure 233 and 234 show images of glass cladded building in Nairobi. It has also explored energy-efficient buildings considering the life cycle of a project. Energy-efficient design techniques during the pre-construction phase of a project, during the construction stage, and post-occupancy phase.

This chapter has also looked at the tropical climate, its characteristics, and an in-depth study of the bioclimatic architecture and analysis of case studies. It has explored the glass-cladded buildings and their impact on the internal environment of designed spaces. Finally, the discussion of occupancy levels of both glass-cladded and bioclimatic buildings.

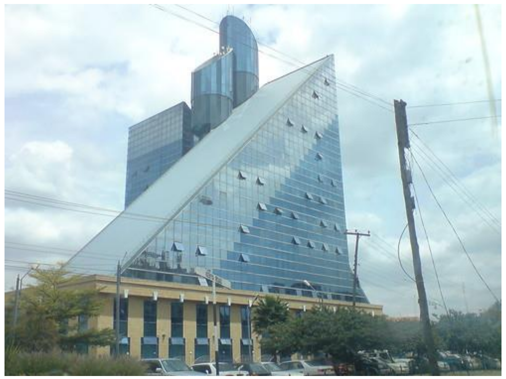


Figure 234 Image showing a glass cladded glass cladded Victoria Towers, Upperhill Nairobi Nairobi.

Source: glass cladded buildings in upperhill nairobi - Bing images

5.1.3 Chapter III: Research Methods

In this chapter, the research's goal, design, research strategy, gathering data, and analytic methods were discussed. It also entails the sampling methods in the area of study; for the sample size for this research, a good number of buildings were studied, and their occupancy and monthly electric consumptions were taken. Three buildings were modelled and an energy simulation was carried out to analyse energy efficiencies. A descriptive investigation to comprehend the efficiency of energy and occupancy levels of buildings in Nairobi using a

Figure 235 Image showing image of Britam Towers, Upperhill, Nairobi

Source: R.9481fb56fa519fc7dbbac916e78bb690 (1500×1000) (bing.com)

Figure 236 Image of Norwich Union, Nairobi. Source: OIP.Ycs9Dwnqj8BMsTjrcdL_nAHaE7 (474×315) (bing.com)

combined technique of both.

The investigation involved the study of energy efficiency and occupancy levels of glass-cladded buildings and bioclimatic buildings. The main techniques for collecting data were interviews, observation, and climatic data recordings, which were then analysed via the use of written narratives, charts, graphs, and tables.

5.1.4 Chapter Four: Finding and Analysis

This chapter highlights the fieldwork findings of the research in Nairobi CBD, Westland's, and Upper Hill. The purpose of this chapter was to investigate the energy efficiency and occupancy levels of office buildings.

5.2 Conclusions and Recommendations Based on Objectives

By summarizing the key research findings and responding to the initial research questions, this part aims to bring the study to a conclusion. This research was anchored on three objectives;

1. To establish existing knowledge on the energy efficiency of bioclimatic buildings in tropical climates with a focus on Nairobi
2. To investigate the energy performance and occupancy levels of glass-cladded buildings and bioclimatic buildings in Nairobi.
3. To make recommendations for guidelines and strategies that can be developed for buildings in Nairobi to make them energy efficient

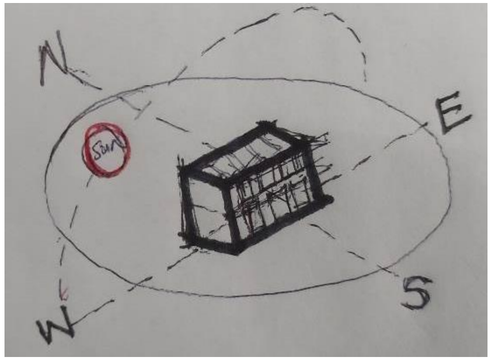


Figure 238 Image showing the orientation of the building.

Source; Author; 2023

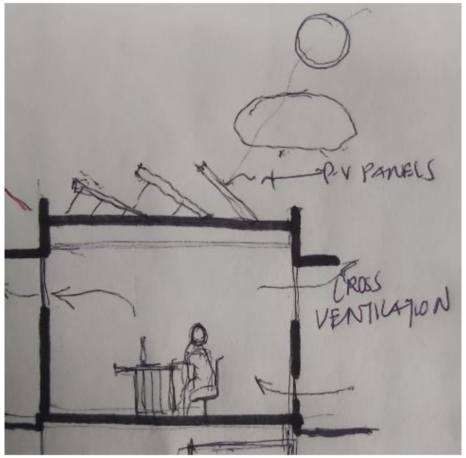


Figure 237 Image illustrating cross ventilation in an office for thermal comfort.

Source: Author 2023

Objective 01: To establish existing knowledge on the energy efficiency of bioclimatic buildings in tropical climates with a focus on Nairobi.

Bioclimatic buildings use design elements and technological advancements that maximize their use of energy and environmental performance. From the study, the author documented several ways that increase the energy efficiency of bioclimatic buildings in tropical climes, where high temperatures and humidity are common:

1. Passive cooling strategies: To reduce the need for mechanical cooling, bioclimatic buildings in tropical areas frequently employ passive cooling strategies. To enhance natural circulation and reduce solar heat gain, these strategies include natural ventilation, cross-ventilation, shading devices (such as overhangs and louvers), and building orientation. Figures 237 -245 highlight some of the strategies.
2. Thermal mass and insulating material: These two elements operate in concert to prevent heat from escaping via walls, roofs, and windows. Thermal insulation is crucial for keeping interior areas cool in warm climates. Temperatures inside buildings can be maintained by using thermal mass materials like concrete, masonry, or adobe which collect solar energy during the day and release it at night.
3. Efficient building envelope: A building envelope with a low solar heat gain coefficient and well-insulated walls, roofs, and windows helps to minimize heat transfer between internal and outside spaces.
4. Natural illumination: Making use of daylighting can cut down on the demand for artificial lighting, which will save energy. Skylights, clerestory windows, and light shelves are frequently used in bioclimatic structures to maximize natural illumination and reduce heat gain.

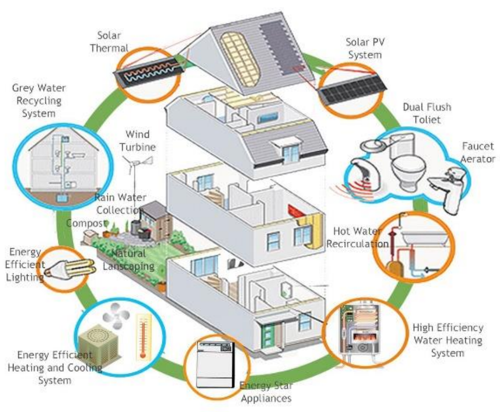


Figure 240 Image illustrating the different energy efficient systems on a building.

Source: energy efficient buildings - Bing images

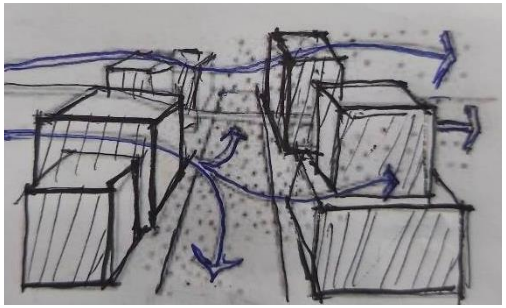


Figure 239 Image showing street canyons lined with buildings of different heights and interspersed with open areas for better air circulation.

Source: Author Modified, 2023

5. Integrating renewable energy systems can help bioclimatic buildings generate their electricity sustainably and lessen their reliance on conventional energy sources. Examples of such systems include solar panels and wind turbines.
6. Water efficiency: To reduce water consumption and the energy needed for water treatment and distribution, bioclimatic buildings frequently use water-efficient technology like rainwater collection, greywater recycling, and low-flow fixtures.
7. Energy-efficient systems and appliances can help bioclimatic buildings use less energy by using energy-efficient HVAC units, lighting fixtures, and appliances.
8. The education and behaviour of building inhabitants can further improve the energy efficiency of bioclimatic structures by teaching them how to use lighting, ventilation, and temperature control appropriately.

Objective 02: To investigate the energy performance and occupancy levels of glass-cladded buildings and bioclimatic buildings in Nairobi

A variety of data gathering, monitoring, analysis, and modelling techniques was used in this research to provide a comprehensive understanding of the energy performance and occupancy levels in glass-cladded buildings and bioclimatic buildings.

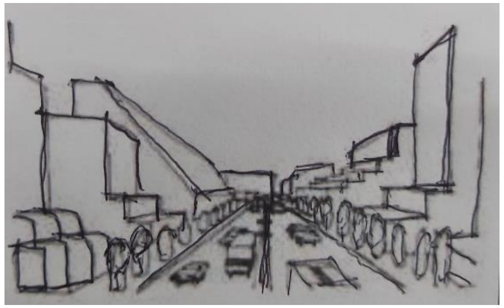


Figure 241 Image showing street canyons with stepped buildings to the back of the streets.

Source: Author modified, 2023

Figure 242 Image showing street arcades, allowing air circulation.

Source: Author modified, 2023

Case studies gathered and analysed from field research contributed valuable insight into the investigation. Glass-cladded buildings and bioclimatic buildings were noted to have different energy performance and occupancy levels.

Although glass-cladded buildings have a modern and aesthetically pleasing design, with curtain walls system, and glass facades, which offer an abundance of natural light and visual connection with the surrounding, they can also present challenges in terms of energy performance. This leads to reliance on mechanical heating and cooling systems, resulting in higher energy consumption and operating costs.

Effects of glare, thermal discomfort, and inconsistent indoor temperature possess another challenge with glass-cladded buildings leading to the discomfort of the occupants.

Bioclimatic buildings, on the other hand, have fared favourably when it comes to energy effectiveness and occupancy rates. To reduce energy use, the structures make use of passive design elements including natural ventilation, thermal mass, and shading devices. This has been observed with reduced bills thus reducing environmental impact. The occupancy levels in bioclimatic buildings have shown some variations, however, an emphasis on energy efficiency and sustainability can attract environmentally conscious occupants who value sustainable working spaces.

Objective 03: To make recommendations for guidelines and strategies that can be developed for buildings in Nairobi to make them energy efficient. To reduce dependency on mechanical cooling systems by incorporating passive design strategies such as orientation, use of sun shading devices, use of thermal chimneys to extract air, high thermal mass, and natural ventilation.

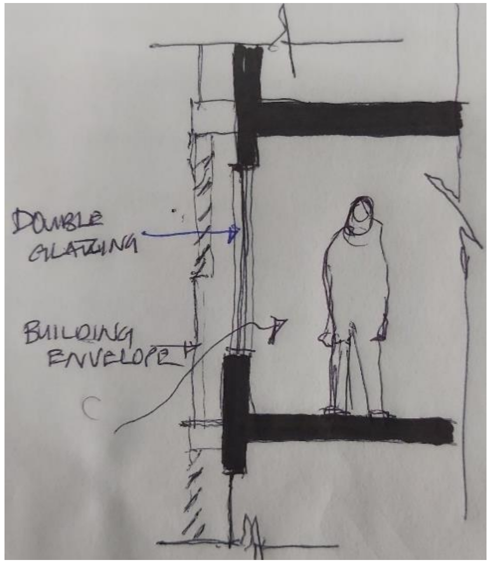


Figure 243 Image showing double skin façades dynamism in the control of natural Ventilation, shading, passive solar and daylighting.

Source: Author modified, 2023

1. Effective Building Envelope: To reduce heat gain and loss, use high-performance insulation, reflective roofing materials, and effective windows.
2. Promote the use of energy-saving lighting fixtures, such as LED bulbs, and encourage natural lighting by strategically placing windows and adding skylights.
3. To offset electricity use and lessen reliance on the grid, promote the construction of renewable energy solutions like solar panels.
4. Building Automation and Controls: Make use of smart building technology like occupancy sensors, programmable thermostats, and building energy management systems to maximize energy utilization.
5. Education and Awareness: To promote awareness of energy-efficient methods and induce behavioural changes, offer professionals and building occupants educational and training programs.
6. Energy Performance Monitoring: Use technologies for tracking and analysing a building's energy usage to pinpoint problem areas and direct energy-saving activities.
7. Building Regulations and Incentives: Create and uphold building regulations that place a high priority on energy efficiency in tropical areas. Provide cash incentives, tax reductions, or accelerated permits for structures that surpass energy efficiency requirements.

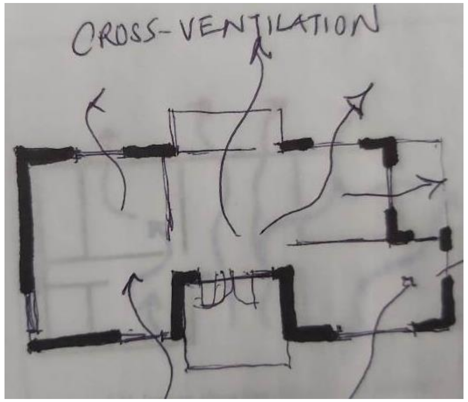


Figure 244 Image showing planning to enhance cross ventilation.

Source: Author Modified, 2023

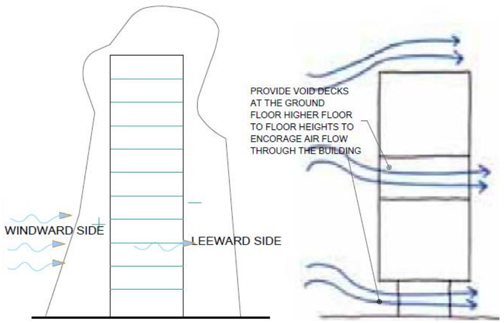


Figure 245 Image showing effect of wind on two different massing.

Source: Author, 2023

5.3 Recommendations

About the findings, several recommendations are made to improve efficiency in buildings and thus increase occupancy levels;

1. **Site Selection**;

- Consider a site where the structure may be placed on an east-west axis.
- Consider a location that receives shading from nearby buildings or trees to the east and west during hot periods.

2. **Site Planning**

- Layout and Orientation: Place the buildings to take advantage of available natural resources including sunlight, prevailing winds, and shade. The requirement for artificial heating and cooling can be decreased by orienting the building to optimize sun gain and limit heat gain.
- Passive Design Techniques: To minimize the need for mechanical systems and cut energy usage, use passive design elements like adequate insulation, high-performance windows, shading mechanisms, and natural ventilation.
- Use landscaping and plants wisely to create shade, lessen the impact of heat islands, and enhance the microclimate in the area around the structure. The need for energy for cooling can be decreased by putting in trees and green roofs.

Figure 246 Image showing Nairobi skyline. Source: gtc towers - Bing images

Figure 247 Image showing Nairobi skyline. Source: Computer-Generated-Image-for-GTC-Nairobi.-Source-GTC.jpg (960×600) (estateintel.com)

- Optimize the layout of the site to reduce energy losses and increase efficiency. To reduce heat island impacts and maximize solar access, think about things like where to put parking lots, roads, and service facilities.
- Integration of Renewable Energy: Look for ways to include renewable energy systems like solar, wind, or geothermal systems into the site plan. Examine the sun and wind potential of the location to decide which renewable energy solutions are most appropriate.
- Public Transportation Availability: By placing the building adjacent to public transportation stops, you can promote the use of it. To lessen dependency on private vehicles, promote bicycle infrastructure and pedestrian-friendly architecture.

3. **Building Form**;

- Visualize an extended rectangle with an east-west long axis.
- Consider a compact design to reduce surface area and building materials.
- Take into account reducing the building's breadth (depth) to maximize cross ventilation and/or daylighting.
- Consider employing an atrium to provide light and vistas to the middle of a big, compact building.
- consider how the façade of a solar-responsive building will change depending on its orientation. The north and south facades should have the most windows, while the east and west should have the least.

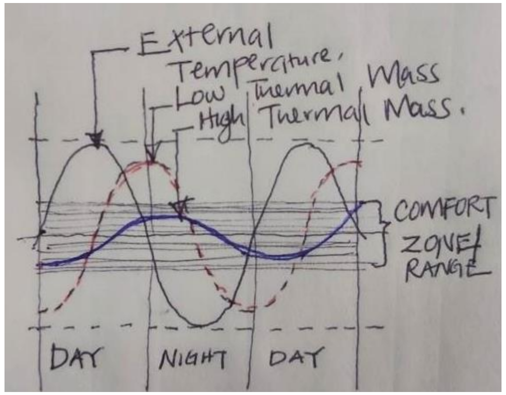


Figure 248 Image showing importance of Thermal mass.

Source: Author Modified, 2023

4. Building layout and appropriate space planning

- On a building's east and west sides, take into account employing buffer spaces (such as damp areas, storage, and fire stairs).
- To save energy and promote healthy exercise, think about prohibiting healthy people from using escalators and elevators while going only to one or two levels. Use attractive, visible stairs instead of the less aesthetic, less noticeable elevators and escalators.
- To make the most of natural light and ventilation, use an open floor design.

5. Building Envelope

- Insulation: adequate insulation is crucial to reduce heat transfer through the walls, roof, and floor, to lessen thermal bridging and heat loss or gain, high-quality insulation materials with a high R-value should be fitted efficiently. Figure 248 shows the importance of thermal mass.
- Selecting energy-efficient windows and glazing systems with strong insulating qualities, low-emissivity coatings, and suitable solar heat gain coefficients (SHGC) is important. Insulation can be improved and heat transfer can be decreased by double or triple glazing with gas fills.
- Make sure the building envelope is effectively air sealed to stop air leakage and infiltration. This improves overall energy efficiency, lowers heat gain or loss, and maintains indoor air quality.

Figure 249 Image of BedZED building.
Source: Bedlington zero building - Bing images

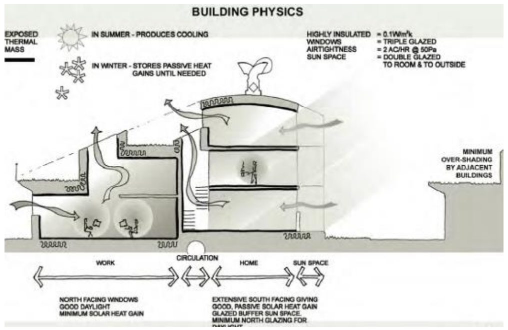


Figure 250 Image showing BedZED passive solar sunspaces on the South side and on the cooler work spaces on the North. Source: Heating, Cooling, lighting,

- Solar shading: Use coverings like awnings, shutters, or overhangs to protect solar heat gain and glare when the sun is at its greatest intensity.
- To hold and absorb heat, use building materials that have substantial thermal mass, such as concrete or masonry. This will control internal temperature swings and lessen the need for heating and cooling.
- Ventilation: Use energy-saving ventilation systems to exchange enough fresh air while reducing energy loss.
- Reflective roofing: To limit heat absorption and lower cooling demand, think about employing reflective roofing materials or cool roof coatings. In hot areas, this can be especially helpful.

6. Choosing energy-efficient building materials

- Low Embodied Energy: Consider materials that have minimal embodied energy. Embodied energy is the total amount of energy consumed during manufacture, transportation, installation, and extraction.
- Encourage construction materials that are sustainable and manufactured from recycled materials, such as recycled steel, reclaimed wood, and recycled glass.
- High Durability: Choose materials that require less maintenance and have extended lifespans.
- Low emissions of VOCs, volatile organic compounds, and non-toxic materials should be used to maintain acceptable indoor air quality.
- Perform a life cycle assessment, also known as an LCA, to analyse the environmental effects of materials from manufacturing to disposal.

Figure 251 Image showing Menara UMNO Building by Ken Yeang and others.

Source: archdaily.com

7. Energy-efficient landscape design

- Choose local or adapted plants that are suited to the environment and need little in the way of water, fertilizer, or pesticide inputs.
- Water Conservation: Use effective irrigation techniques to provide water to plant roots directly and to minimize water wastage, such as drip irrigation or smart controllers.
- Windbreaks & Shade: Utilize trees, bushes, and trellises to create shade for buildings, windows, and outdoor living and working areas.
- Permeable Surfaces: Use permeable paving materials, like interlocking pavers or permeable concrete, to promote rainwater infiltration and reduce stormwater runoff.
- Outdoor lighting fixtures: Use LED lights, which use less electricity and have a longer lifespan, as since they are energy-efficient and long-lasting. Use timers or motion sensors to control lighting and save electricity.

8. Use of renewable energy resources

- Solar Photovoltaic (PV) Systems: Install solar panels on the building's roof or facades to capture sunlight and turn it into power. Solar PV systems can significantly reduce a building's electricity use.
- Wind Turbines: In suitable locations, wind turbines can be set up to harness the kinetic energy of the wind to produce electricity. To help with the building's energy requirements, small wind turbines can be incorporated into the design or placed nearby.
- Geothermal Systems: Use geothermal heat pumps to heat and cool your home by utilizing the steady temperature of the earth or water.
- Make use of biomass energy to generate heat or electricity from organic resources like pellets of wood, agricultural waste products, or specially designed energy crops. Areas of Further Research

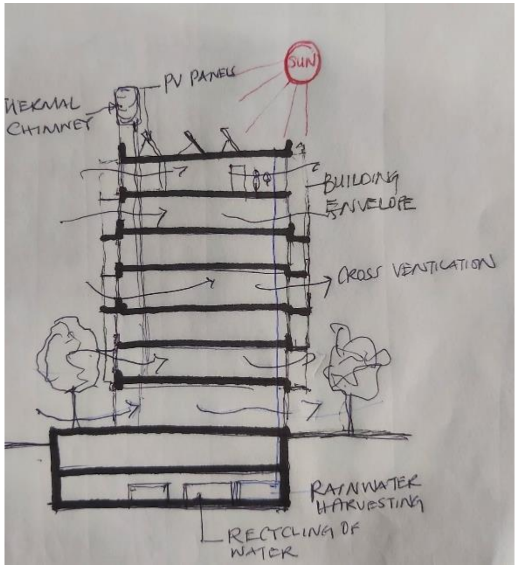


Figure 252 Image showing Energy Efficiency strategies.

Source: Author modified, 2023

This study focussed on an investigation of energy efficiency and occupancy levels of glass-cladded and bio-climatically designed buildings; - a case of CBD, Nairobi. Similar research can be carried out in other cities, for example, Mombasa and Kisumu. Further research can be carried out to investigate energy efficiency in high-rise residential buildings and shopping malls in urban centres.

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A-01 LIST OF REFERENCES

B-02 QUESTIONNAIRE

AN INVESTIGATION OF ENERGY EFFICIENCY AND OCCUPANCY LEVELS OF GLASS CLADDED AND BIOCLIMATICALLY DESIGNED BUILDINGS; - A CASE OF CBD, NAIROBI.

I. ENERGY EFFICIENCY
   a. Space between neighboring buildings.
   b. Check the no. of floors
   c. Glass-to-wall ratio. 25%, 50%, 75% & 100%
   d. Type of glass. Clear, filmed, single or double glazed
   e. Renewable energy sources; solar, water treatment and recycling, etc.
   f. Reliance on K.P.L.C. / OR Generator
   g. Energy consumption per month for the building. Bills rating kWh etc.
   h. Vents / operable windows
   i. Presence of ACs, fans, wind cowls,

II. OCCUPANCY
   a. What is the occupancy levels? 0%, 50%, 75% and 100%. Available space for rent
   b. Rent per m2
   c. Type of business per floor

BUILDING X (Type of business)				
OFFICE	RETAIL	INSTITUTIONAL	F&B	OTHERS

QUESTIONNAIRE

General Information

1. Location
2. Building name
3. Date designed
4. Architect

Energy Efficiency

1. What is the Space between the target and the neighboring buildings? None, Small, medium, Large
2. What is the total area of the building
3. What is the no. of floors?
4. What is the estimated glass-to-wall ratio of the building? Is it 25%, 50%, 75% & 100%
5. What is the type of glass installed on the façade, ie Clear, filmed, single or double glazed?

6. Are there Renewable energy sources; solar panels, water treatment, recycling, or any other?
7. What is the main source of energy? K.P.L.C. / OR Generator, Solar, or any other
8. What is the estimated level of Energy consumption per month for the building? Bills rating kWh etc. for the year 2022
9. What is the occupancy rate at this time? 0%, 50%, 75% and 100%.
10. What is the no. of people per m2? Or per floor area?
11. What is the estimated tenant rent per m2?
12. Who are the main occupants or the type of business found in the building per floor? Commercial, Institutional, or offices
13. What is the duration of occupancy or lease periods?
14. Does it matter to you whether a building is glass-cladded building or bio-climatically designed?
15. To what extent do you think tenant spaces are comfortable to work in? thermal comfort of occupants.